Circular economy and office fit-out:

an analysis for office fit-out processes based on material flows

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UCL

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University College London, UK
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Declaration

I, Miguel Casas-Arredondo, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.
Abstract

The built environment is the most resource intensive sector of the economy, accounting for over a half of extracted materials and around one third of total waste generated. Within the built environment the most recurrent replacements of building materials and components take place during fit-out, which is the process of installing interior fittings, fixtures and finishes. These materials and components are more frequently replaced in non-domestic buildings, so non-domestic building fit-outs are responsible for recurrent consumption of materials and generation of waste. However, these processes tend to go unnoticed and unmeasured in the research about sustainable buildings. The present work aims to study this research gap and to analyse the potential for fit-outs to become more sustainable. The approach of this project ties in closely to the concept of circular economy, where materials are kept at their most useful state for as long as possible.

This work analysed fit-out processes within UCL Estates and London through mixed research methods, including quantitative material flow analyses and the qualitative analysis of interviews. In total, 31 supply-chain stakeholders related to the fit-out industry were contacted and five fit-out case studies as well as two Waste Contractor case studies were considered. The structure of the fit-out supply chain was mapped out and the roles and interactions of the relevant stakeholders were analysed. Key materials and components installed and removed at fit-outs projects were defined while waste streams generated were measured, and their paths and final destinations were traced. A socio-technical analysis was developed for office and higher education institution building fit-outs and used to recognise key incentives and mechanisms that encourage higher rates of reuse, remanufacture and closed-loop recycling, from the design stage of building fit-outs and products to the treatment of wastes.

It was concluded that the fit-out supply-chain generally showed a linear tendency in terms of both decisions and material flows, and a “reuse third party” in the supply chain showed to facilitate salvaging building components otherwise treated as waste. The rates of replacement for building products were generally shorter than their lifespans and the main barriers to potential reuse were both the lack of size standardisation and the lack of modular installation. Material flow analyses conducted for fit-out case studies showed that most waste streams were downcycled into products or uses that require inferior material quality and little waste was closed-loop recycled. Mixed waste was the highest-mass waste stream generated, followed by plasterboard and wood.
Impact statement

Non-domestic building fit-outs, such as those in office and higher education institution buildings, represent a significant consumption of materials and a large source of waste, in a world with limited virgin resources and decreasing space in which to dispose of waste.

This work is one of the first to study building fit-out processes and it is currently the most comprehensive analysis conducted on this topic. The research addresses a knowledge gap through merging quantitative and qualitative approaches to obtain a socio-technical perspective on the issue. The research findings provide a better understanding of fit-out processes and aim to raise awareness on a set of key challenges in the fit-out and refurbishment industry. While the research is based in the UK, some findings are transferable to the European Union and to a global scale.

The work provides a background for further academic research on an under-studied subject and suggests new research questions and research tools. Policy and practical recommendations are proposed to support the transition of the fit-out industry towards a circular economy.

Such recommendations fall under different dimensions, including regulation and assessment (e.g. the identification of shortcomings in the waste-management regulatory framework and the outline of fit-out benchmarking indicators), information (e.g. a methodology for pre-refurbishment audits), organisation (e.g. circular logistic alternatives through the use of third parties in the supply chain) as well as technical and design issues (e.g. mechanisms for better onsite waste segregation and design improvements for more “circular” building fit-outs and products).

The research objective and findings are aligned with the Circular Economy Action Plan implemented by the European Commission (2015), which has set an agenda for the recovery of valuable resources and adequate waste management in the construction and demolition sector.

Parts of the work were presented in two seminars for dissemination and feedback purposes. Key findings were presented and published at PLATE conference on product lifetimes, and they were also published in the Journal of Cleaner Production (see Appendix A).
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<td>ATF</td>
<td>Authorised Treatment Facility</td>
</tr>
<tr>
<td>BAMB</td>
<td>Buildings as Material Banks</td>
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<tr>
<td>BIM</td>
<td>Building Information Modelling</td>
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<tr>
<td>BREEAM</td>
<td>Building Research Establishment Environmental Assessment Method</td>
</tr>
<tr>
<td>CBA</td>
<td>Cost-Benefit Analysis</td>
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<tr>
<td>CEW</td>
<td>Circular Environmental Weight</td>
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<tr>
<td>CLSC</td>
<td>Closed-Loop Supply Chain</td>
</tr>
<tr>
<td>CLT</td>
<td>Cross-Laminated Timber</td>
</tr>
<tr>
<td>C&amp;D</td>
<td>Construction and Demolition</td>
</tr>
<tr>
<td>CD&amp;E</td>
<td>Construction, Demolition and Excavation</td>
</tr>
<tr>
<td>DEFRA</td>
<td>(UK’s) Department for Environment, Food and Rural Affairs</td>
</tr>
<tr>
<td>DfD</td>
<td>Design for Disassembly/Deconstruction</td>
</tr>
<tr>
<td>EA</td>
<td>(UK’s) Environment Agency</td>
</tr>
<tr>
<td>EC</td>
<td>Embodied Carbon</td>
</tr>
<tr>
<td>EfW</td>
<td>Energy from Waste</td>
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<tr>
<td>EIF</td>
<td>Environmental Impact Factor</td>
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<tr>
<td>EPD</td>
<td>Environmental Product Declaration</td>
</tr>
<tr>
<td>EPR</td>
<td>Extended Producer Responsibility</td>
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<tr>
<td>EU</td>
<td>European Union</td>
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<tr>
<td>EW</td>
<td>Environmental Weight</td>
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<tr>
<td>EWC</td>
<td>European Waste Catalogue</td>
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<tr>
<td>GDP</td>
<td>Gross Domestic Product</td>
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<tr>
<td>GFA</td>
<td>Gross internal Floor Area</td>
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<td>GHG</td>
<td>Green House Gas</td>
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<td>GPM</td>
<td>Good Practice Measure</td>
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<tr>
<td>HEI</td>
<td>Higher Education Institution</td>
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<tr>
<td>HVAC</td>
<td>Heating, Ventilating and Air-Conditioning</td>
</tr>
<tr>
<td>H&amp;S</td>
<td>Health and Safety</td>
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<tr>
<td>IoT</td>
<td>Internet of Things</td>
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<tr>
<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
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<tr>
<td>IPP</td>
<td>Integrated Product Policy</td>
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<tr>
<td>ISO</td>
<td>International Society for Standardization</td>
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<tr>
<td>KPI</td>
<td>Key Performance Indicator</td>
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<tr>
<td>LCA</td>
<td>Life-Cycle Analysis/Assessment</td>
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<tr>
<td>LCI</td>
<td>Life-Cycle Inventory</td>
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<tr>
<td>LEED</td>
<td>Leader in Energy and Environmental Design</td>
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<tr>
<td>LoW</td>
<td>List of Wastes</td>
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<tr>
<td>MDF</td>
<td>Medium-Density Fibreboard</td>
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<tr>
<td>MFA</td>
<td>Material Flow Analysis</td>
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<tr>
<td>MRF</td>
<td>Material Recovery Facility</td>
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<tr>
<td>M&amp;E</td>
<td>Mechanical and Electrical</td>
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<tr>
<td>Acronym</td>
<td>Description</td>
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<tr>
<td>O&amp;M</td>
<td>Operation and Maintenance</td>
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<tr>
<td>PPE</td>
<td>Personal Protection Equipment</td>
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<tr>
<td>PRA</td>
<td>Pre-Refurbishment Audit</td>
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<tr>
<td>PRO</td>
<td>Producer Responsibility Organisation</td>
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<tr>
<td>PVC</td>
<td>Polyvinyl Chloride</td>
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<tr>
<td>RAF</td>
<td>Raised Access Floor</td>
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<tr>
<td>RC</td>
<td>Ratio of Circularity</td>
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<tr>
<td>RCLR</td>
<td>Remanufacture and Closed-Loop Recycling</td>
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<tr>
<td>RDF</td>
<td>Refused-Derived Fuel</td>
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<tr>
<td>RFID</td>
<td>Radio Frequency Identifier/Identification</td>
</tr>
<tr>
<td>RWG</td>
<td>Rate of Waste Generation</td>
</tr>
<tr>
<td>ROWS</td>
<td>Ratio of Onsite Waste Segregation</td>
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<tr>
<td>SD</td>
<td>Standard Deviation</td>
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<tr>
<td>SKA</td>
<td>SKA Rating system</td>
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<tr>
<td>SNRHW</td>
<td>Stable Non-Reactive Hazardous Waste</td>
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<tr>
<td>SWMP</td>
<td>Site Waste Management Plan</td>
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<tr>
<td>TfL</td>
<td>Transport for London</td>
</tr>
<tr>
<td>UK</td>
<td>United Kingdom</td>
</tr>
<tr>
<td>USA</td>
<td>United States of America</td>
</tr>
<tr>
<td>VOC</td>
<td>Volatile Organic Compounds</td>
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<tr>
<td>WEEE</td>
<td>Waste Electrical and Electronic Equipment</td>
</tr>
<tr>
<td>GWP</td>
<td>Gross World Product</td>
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<tr>
<td>WFD</td>
<td>Waste Framework Directive</td>
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## Glossary

<table>
<thead>
<tr>
<th>Building component</th>
<th>any element installed in a building that provides a functional or aesthetic utility (e.g. fittings and furniture), usually comprised of more than one material</th>
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<tr>
<td>Building material</td>
<td>any material that constitutes a building component or that is adhered to a building or to a building component</td>
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<tr>
<td>Building product</td>
<td>includes any type of building material or component</td>
</tr>
<tr>
<td>Circularity</td>
<td>a behaviour in which a resource, product, process or system maintains material or functional value over time</td>
</tr>
<tr>
<td>Circularity potential</td>
<td>the capability of a resource or product to maintain its material or functional value over time</td>
</tr>
<tr>
<td>Closed-loop recycling</td>
<td>when a product or material is recycled into the original product or into the original constituent material(s) maintaining the material and functional value</td>
</tr>
<tr>
<td>Closed-loop supply chain</td>
<td>a supply chain with reverse flows of used products back to manufacturers</td>
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<tr>
<td>De-fit/Strip-out</td>
<td>the process of removing fittings, finishes and/or furnishings inside a building</td>
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<tr>
<td>Downcycling</td>
<td>when a product or material is converted into a different product or resource and the material’s physical properties are impoverished</td>
</tr>
<tr>
<td>Finish</td>
<td>outer material layer added to a building’s surface (e.g. floor or wall) generally for aesthetic purposes but can also aim to improve the acoustic, moisture or thermal performance</td>
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<tr>
<td>Fit-out</td>
<td>the process of removing and installing interior building materials and components. These building elements may include partitions, doors, flooring, ceiling, finishes, fittings, furniture, equipment, and services</td>
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<tr>
<td>Fitting</td>
<td>something attached to a building’s surface, furniture or equipment (also known as fixture)</td>
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<tr>
<td>Fixture</td>
<td>something usually permanently attached to a building</td>
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<tr>
<td>Functional value</td>
<td>the level of utility of a product relative to its original utility (i.e. how well a product can perform compared to when it was new)</td>
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<tr>
<td>Furnishing</td>
<td>includes items such as furniture, curtains and decorative accessories inside a building</td>
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<tr>
<td>Material passport</td>
<td>a unique identifier embedded in a building product to be able to track and inventory the item</td>
</tr>
<tr>
<td>Material value</td>
<td>the degree to which the set of physical and/or chemical properties that make a material useful or desirable are maintained, relative to when it was produced or manufactured</td>
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<tr>
<td>Modular</td>
<td>constructed with standardised dimensions for flexibility in use and/or made from a set of separate parts that can be assembled to form a larger object</td>
</tr>
<tr>
<td>Re-fit</td>
<td>the process of installing fittings, finishes and/or furnishings inside a building</td>
</tr>
<tr>
<td>Reclaim/Salvage</td>
<td>to keep or preserve an item for further reuse</td>
</tr>
<tr>
<td>Recycle</td>
<td>when a product or material is reprocessed and converted into the original or a different product</td>
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<tr>
<td>Term</td>
<td>Definition</td>
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<td>-----------------</td>
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<tr>
<td>Refurbishment</td>
<td>any building works that modify the building or space, aiming to increase its economic value or social desirability, update it to current standards, improve its performance, or adapt it to a different use</td>
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<tr>
<td>Reuse</td>
<td>to use an item after end of life for the same purpose it was intended for. Reuse can be done by the original user or by a new user</td>
</tr>
<tr>
<td>Re-user</td>
<td>a person or entity that reuses a product other than the previous user</td>
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<tr>
<td>Remanufacture</td>
<td>the process of returning a product to its original functional or aesthetic state by replacing worn-out components with new or used ones</td>
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<tr>
<td>Repurpose</td>
<td>to reuse an item for a different use than the original one</td>
</tr>
<tr>
<td>Retain (in situ)</td>
<td>to maintain the location and purpose of an installed item</td>
</tr>
<tr>
<td>Reverse logistics</td>
<td>the process of transporting end-of-life items from their current location with the purpose of capturing value (e.g. through reuse or remanufacture)</td>
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<tr>
<td>Take-back scheme</td>
<td>a service provided by the manufacturer or retailer in which they collect their end-of-life products from the user</td>
</tr>
<tr>
<td>Waste</td>
<td>any substance or object which the holder discards or intends or is required to discard (Council Directive 2008/98/EC, 2008)</td>
</tr>
<tr>
<td>Waste stream</td>
<td>a category of waste which includes items that are the same or a similar product (e.g. tyres or electrical/electronic equipment), items made mostly of the same type of material (e.g. metal or plastic) or items which contain a particular substance (e.g. asbestos or gypsum)</td>
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1 Introduction

1.1 The problem with building fit-out

Rising environmental concerns particularly around climate change, environmental damage, and resource depletion, documented by the Intergovernmental Panel on Climate Change (IPCC, 2014) and others in various reports, have led governments worldwide to pursue a less carbon and resource intensive economy. The UK government enacted legislation to reduce carbon emissions by 80% by 2050 (UK Government, 2017) and published a Circular Economy Package (UK Government, 2020) to address both the reduction and the recovery of waste.

The built environment accounts for 35% of greenhouse emissions in the European Union (European Commission, 2011), including emissions associated with operational energy use and emissions embedded in building materials and components. Construction also represents the most resource intensive sector of the economy, accounting annually in the UK and the European Union for more than 50% of all extracted materials (BRE, 2008; European Commission, 2011) and over 32% of total waste generated (EEA, 2012; DEFRA, 2020). The extraction and transportation of these materials cause environmental damage and resource depletion (Tukker and Jansen, 2006), and a large proportion of these resources become waste (Rose, C. M, 2019; Eurostat, 2019b), leading to additional environmental impacts. The strategy for Sustainable Construction (UK Government, 2008) was launched as part of the UK’s Sustainable Development Strategy (UK Government, 2005) to promote a reduction of construction, demolition and excavation (CD&E) waste sent to landfill.

Building fit-outs pose a challenge for reducing resource consumption and waste generation in the built environment, since these practices represent the most recurrent replacement of building materials and components. Building fit-out is the process of (removing and) installing interior building materials and components, which may include floor, wall and window coverings, partitions, doors, furniture, equipment, and sometimes mechanical and electrical (M&E) services (Cole and Kernan, 1996; Forsythe, 2010). Prior to the installation of new building products (re-fit), the interior space is normally stripped-out (de-fit) and most products removed end up as waste.

The replacement of these components is more frequent in non-domestic buildings, where they can be replaced every 3-10 years (Trucker and Treloar, 1994; Roussac et al., 2008; Forsythe and Wilkinson, 2014). An outgoing tenant may remove the fit-out and the new tenant will reinstall all these fittings, fixtures, and finishes. Accordingly, fit-outs account for a significant amount of embodied carbon emissions and waste generated throughout the life-cycle of a building due to recurrent product replacement. Regardless of these facts, office building fit-outs tend to go unnoticed and unmeasured in the debate about sustainable buildings (Forsythe and Wilkinson, 2014).

It is clear that there is a current need to channel more effort into the area of building fit-outs to make them more sustainable. There are available certification methods applicable to fit-outs, but they have low uptake and do not fully cover the circular economy concept, which aims to keep materials in a high-value state by repairing, reusing, remanufacturing and high-
quality recycling (EMF, 2015a; Geissdoerfer et al., 2017). Growing environmental concerns and the gradual increase of the UK’s Landfill Tax certainly encourage stakeholders to pursue waste recycling instead of landfilling (Seely, 2009). However, most fit-out waste gets downcycled, since the original materials or components are generally not designed with recycling or reusing in mind (McDonough and Braungart, 1994).

1.2 Thesis aims and structure

The focus of this work is around material flows in non-domestic building fit-outs. Decision flows are also within this scope as these can potentially hinder or support the resource efficiency in fit-out practices. Namely, this work analyses fit-out projects within UCL Estates and London, paying close attention to material and decision flows. The main research question is ‘how can building fit-outs become more circular’, and thus the main research aim is to identify potential improvements in the fit-out process and the design of building products to maintain the value of materials as high, and for as long, as possible. The specific objectives to address this issue are: i) to map out the stakeholders within the fit-out supply chain, ii) to define the function and inter-relations of stakeholders across the fit-out industry, iii) to determine key building products installed and removed during fit-out processes, iv) to identify and measure the waste streams generated in the process, v) to trace paths and destinations of wastes from fit-out case studies, and vi) to identify key incentives and barriers around circularity in the fit-out industry.

The thesis is divided into seven chapters. After this introduction, Chapter 2 contextualises the research problem providing an overview of the circular economy, waste management, and key aspects around building fit-outs. Chapter 3 covers the research methodology, and Chapter 4 presents the results from the methodological approach, including the findings from the fit-out case studies. Chapter 5 analyses and discusses the results, providing common characteristics of building fit-outs and particular findings from case studies. Lastly, Chapter 6 summarises the key findings along with the corresponding recommendations, and it touches on opportunities for future work.
2 Literature review

2.1 Introduction to literature review

This chapter presents the literature review carried out for this work. The research questions presented in the introduction are partly addressed here. No studies were found concerning stakeholder inter-relationships around material flow in the fit-out supply chain, and little work has been published in relation to waste management in the particular area of building fit-outs. However, there is a consensus around the viability of certain mechanisms to support circularity in the built environment, such as designing in layers, engaging in closed-loop supply chains and following assessment methods right from the earliest stages of a building project.

First, an overview of the circular economy is provided in section 2.2, touching on key aspects of this concept. Section 2.3 covers issues related to the convergence of circular economy and building fit-outs. Section 2.4 presents an overview of waste management within a European and UK context. Section 2.5 introduces key elements around waste management in building fit-outs. Lastly, an outline of the assessment mechanisms applicable to building fit-outs is given in section 2.6.

2.2 Overview of the circular economy

2.2.1 A circular model to replace our linear economy

Today’s economy follows a predominantly linear model, in which we take resources, make products, use these products and finally dispose of them, creating a habit of recurrent replacement. This model has its origins in the Industrial Revolution (Andrews, 2015) and has grown ever since. In fact, this economic dynamic helped overcome the Great Depression after 1930, when the concept of “planned obsolescence” was coined (London, 1932), and manufacturers boosted demand by making products with shorter lifespans and by changing consumers’ mindsets, convincing them that new is better (Webster, 2015).

Many manufacturers still tend to build in the obsolescence of their products to promote the replacement of obsolete items and increase sales (Prakash et al., 2016). The obsolescence of products can be in the form of: 1) mechanical obsolescence: defects due to lack of performance of materials or components; 2) functional obsolescence: lack of interoperability of software and hardware; 3) psychological obsolescence: the desire for a new device, though the old one still works; and 4) economic obsolescence: imbalance between repair costs and the cost of new products (Prakash et al., 2016; Ober et al., 2017).

The linear economic model requires constant growth to thrive and relies on large quantities of cheap, easily accessible materials and energy; as such, our use of engineered material has increased by four to fifteen times in the last 50 years (Allwood and Cullen, 2012). However, this model is reaching its physical limits as global population is rapidly increasing and given that planet Earth is a closed system where practically nothing goes in or out (Boulding, 1966). On one hand, the supply of natural resources and energy is generally becoming less accessible

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1 In the last 50 years, World Gross Product (WGP) has grown over ten times and WGP per capita has grown almost four times (EPI, 2012). However, levels of happiness and life satisfaction have not increased concurrently with the WGP (Goosssens et al, 2007).
and more expensive (Allwood and Cullen, 2012; Grierson; 2017), which leads to both price volatility and supply risk (EMF, 2015c). On the other hand, the environmental pressures of extracting natural resources and using the biosphere to dispose of waste are becoming critical, such as climate change, loss of biodiversity and natural capital, land degradation, and air and ocean pollution (EMF, 2015c).

The circular economy is a model proposed to substitute the current ‘take-make-dispose’ scheme and decoupling the environmental pressures from economic growth (Ghisellini, 2015). The concept of circular economy is characterised, more than defined, as “an economy that is regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times” (EMF, 2015a; 2015c), where materials flow in one of two cycles: biological (can be safely decomposed through the biosphere) or technical (non-biodegradable, kept at high quality in their own industrial cycle and away from the biosphere) (Webster, 2015).

The circular economy rests on three key principles (EMF, 2015b), as shown in Figure 2.1:

1. preserve and enhance natural capital by controlling finite stocks and balancing renewable resource flows;
2. optimise resource yields by circulating products, components, and materials at the highest utility at all times, in both technical and biological cycles;
3. foster system effectiveness by revealing and designing out negative externalities.

![Figure 2.1: Dynamics of the circular economy in an industrial system (EMF, 2015a).](attachment:figure2.1.png)
Therefore, circular economy is as “a continuous positive development cycle that preserves and enhances natural capital, optimises resource yields and minimises system risks by managing finite stocks and renewable flows” (EMF, 2015c). In a circular economy model there is no such thing as waste, so products are designed to last, to be repaired, remanufactured, reused, and closed-loop recycled (EMF, 2015a; 2015b; Geissdoerfer et al., 2017); and this model lies in designing well products to facilitate disassembly and reuse, and structuring business models so manufacturers can reap rewards from collecting and remanufacturing, or redistributing end-of-life products (Cheshire, 2016).

2.2.2 Development of the concept of circular economy

The ideas of circular economy have various roots. Boulding (1966) started to grasp the concept as he contrasted the open economy of the past with its seemingly unlimited resources with the closed economy of the future with limited reservoirs either for extraction or pollution, in which humankind “must find [their] place in a cyclical ecological system”. Schumacher (1973) was one of the first economists to question the appropriateness of using gross national product to measure human well-being, and he disputed materialism, “an attitude to life which seeks fulfilment in the single-minded pursuit of wealth”, as it contains within itself no limiting principle, while the environment in which it is placed is strictly limited. Stahel (1976) studied the impacts of product life extension arguing that it constitutes a substitution of energy for labour, and of centralised factories for decentralised workshops. As well, Stahel is credited with having coined the expression “cradle to cradle” as he envisioned an economy in loops and its impact on job creation, economic competitiveness, resource savings, and waste prevention. Based on Boulding’s work, Pearce and Turner (1990) introduced the term of “circular economic system” and pointed out that a traditional open-ended economy was developed with no built-in tendency to recycle, which was reflected by treating the environment as a waste reservoir. Lyle (1994) developed ideas on regenerative design that could be applied to all systems, while McDonough (who studied with Lyle) and Braungart (1994) later on proposed to transform products and processes in such a way that there are workable relationships between ecological systems and economic growth and developed the Cradle-to-Cradle concept and product certification.

The Ellen MacArthur Foundation (EMF, 2019) was established in 2010 with the aim of accelerating the transition to the circular economy and establishing it on the agenda of decision makers across business, government and academia. This organisation has published several reports and books on the topic and conducts an annual international conference (ThinkDIF, 2019). Along with Granta (2019), the Ellen MacArthur Foundation developed the Material Circularity Indicator, which aims at comparing the extent to which linear flows have been minimised and restorative flows maximised for a product’s life-cycle, and how long and intensively the product is used compared to a similar, industry-standard product (EMF, 2017a; 2017b). The EMF estimates that shifting to a circular model would be a $706 billion USD economic opportunity world-wide (Hepler, 2016).

The European Commission (2015) implemented the Circular Economy Action Plan in 2015 to support Europe’s transition towards a circular economy and to promote sustainable economic growth while generating new jobs. The action plan sets out several measures to “close
the loop” of product life-cycles from production and consumption to waste management. It also identifies five priority sectors to boost the transition; namely, plastics, food waste, critical raw materials, biomass and bio-based materials, and construction and demolition (C&D) (European Commission, 2019a). Under the Circular Economy Action Plan, the European Commission aims to support repairability, durability, and recyclability of products, to develop quality standards for secondary raw materials, to take actions to ensure improved recovery of valuable resources and adequate waste sorting and management in the C&D sector, and to facilitate the environmental performance assessment of buildings (European Commission 2015; 2019a).

In the Web of Science (2019), the number or journal articles on the topic of circular economy showed a tenfold growth in 10 years. In 2006, three articles were published on the topic worldwide, while more than 100 papers were published in 2016 (Geissdoerfer et al., 2017). In this time interval, China published the largest number of articles on the topic (124 publications), followed by the UK (43) and Netherlands (30) (Geissdoerfer et al., 2017).

Pomponi and Moncaster (2017) carried out a literature review on circular economy in the built environment and propose a three-tier level distribution: macro (cities and neighbourhoods), meso (buildings) and micro (assemblies and components). The present research takes place at a meso and micro level. Likewise, these authors propose six dimensions in which research on this broad topic can be done: environmental, technological, economic, societal, governmental, and behavioural. An adaptation of these dimensions was used in subsection 5.8.3 to classify the opportunities and barriers for circular fit-out.

2.2.3 Circular economy and sustainability

The circular economy can be viewed as a condition for sustainability (Geissdoerfer et al., 2017), which is an older concept and it is defined as the “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Keeble, 1988). Both notions, sustainability and circular economy, emphasise intra- and inter-generational commitments motivated by environmental hazards, and they also share an essentially global perspective that leads to joint responsibilities and to the coordination between multiple agents. Both concepts rely on regulation and, increasingly, on the design of incentive structures and the innovation of business model as a pathway to the necessary socio-technical transitions (Geissdoerfer et al., 2017).

Sustainable development is based on three pillars, in which both economy and society are constrained by environmental limits (Cato, 2012). This scheme aligns with the “triple bottom line”, which is an accounting framework consisting of three parts: profit, people and planet (Elkington, 2018). While circular economic systems are beneficial for different sustainability dimensions like resource productivity, job creation and gross domestic product (GDP) growth (European Commission, 2014b), the idea of circular economy commonly fails to integrate other dimensions (Murray et al. 2015), especially the social one where the reference is mostly to job creation, and there seems to be no clear understanding of the extent to which the circular economy could contribute to subjective well-being (Frey and Stutzer, 2001, as cited in Geissdoerfer et al., 2017). There are also negative relationships between “circularity” and sustainability, such as the technical difficulties of material closed cycles in
combination with growing demand or the energy required to maintain the value of materials through closed-loop recycling (Allwood, 2014).

2.2.4 The concept of value in a circular economy
The concept of value is crucial in a circular economy; however, there is not a clear definition of value in this context. The idea of value has been debated since Aristotle (Vargo et al., 2008), and the most universal definition, which includes both “use value” and “exchange value” (Bowman and Ambrosini, 2000; Vargo et al., 2008), comes from a commercial (or trade) approach. This definition of value is a measure expressed in currency and is equal to the cost of a product or service plus a subjective marginal value, which depends on the owner’s or buyer’s value system (Neap and Celik, 1999). Apart from being a measure of the monetary worth, value can reflect the worth of products and services under different criteria, such as the level of utility of a product or the avoidance of environmental impacts that keeping a product may represent, against discarding it and producing new products or raw materials. The concept of “value creation” thus represent the performance of actions that increase the worth (in any scale) of goods, services or businesses (Business Dictionary, 2019).

In this work, the value of building products is considered in terms of functional and material value, relative to the original functional and material “worth” when products are new. Functional value is defined as the level of utility of a product relative to its original utility (i.e. how well a product can perform compared to when it was new). Material value is defined as the degree to which the set of physical and/or chemical properties that make a material useful or desirable are maintained, relative to when it was produced or manufactured.

2.3 Fit-outs and circular economy
2.3.1 Introduction to building fit-out
The junction of circular economy with building fit-outs contains different elements to consider, such as waste management, sustainable building products, design for adaptability, closed-loop supply chains and new business models. These elements are covered next after briefly contextualising the definition of building fit-out.

There are several terms currently used to refer to the activity of modifying a building or space. Many of these terms are often used interchangeable and have become largely undistinguishable (Mansfield, 2002). For this work, the terminology is defined as follows. Renovation and refurbishment are considered synonyms and thus only the term refurbishment is used in this work. Refurbishment includes any building works that modify the building or space, aiming to increase its economic value or social desirability (RICS, 1973), update it to current standards (CIOB, 1987), improve its performance, or adapt it to a different use. Building fit-outs and retrofits are both types of renovation or refurbishment. Fit-out relates to a refurbishment which takes place primarily in the interior of a building (infill), while retrofit entails a renovation that improves the thermal, hygric, acoustic or energy performance of the building.

In a more extensive definition, building fit-out is the process of removing and installing (mostly) interior building components and materials. These building elements may include
partitions, doors, flooring, ceiling, finishes, fittings, furniture, equipment, and M&E services.

There is a large potential to integrate circular economy characteristics in building fit-out processes as these account for the most recurring replacement of products within the built environment. Buildings can be seen and analysed in different layers (as shown in Figure 2.2), depending on function and replacement rate. Brand (1994) proposes six different layers: Site (geographical setting), Structure (load-bearing elements), Skin (building envelope), Services (wiring, plumbing, HVAC), Space plan (walls, partitions, ceiling, floor), and Stuff (furniture and equipment). These layers have increasing rates of replacement, from the Site being permanent, the Structure being able to last 300 years, to the Space plan and Stuff being replaced every three years or so.

Fit-outs relate to the most frequently replaced layers: Skin (sometimes), Services, Space plan and Stuff, and therefore can represent the highest cost, energy consumption, and waste production in the life-cycle of a building. Brand (1994) demonstrates that in a 50-year cycle, the changes within a building cost three times more than the original building. Liljenstrom and Tove (2016) report that an office fit-out may produce as much as 74.5 kgCO$_2$eq per m$^2$. Multiple authors state in a building life-cycle, fit-outs eventually outweigh the embodied energy used to construct the building (Cole and Kernan, 1996; Zabalza et al, 2009). There are no analogous findings for waste production from fit-outs in a building life-cycle, but the average waste generation in office fit-outs is estimated to be 6.3 t for every 100 m$^2$ of floor area (BBP et al., 2015). Non-residential buildings may have 30 to 40 fit-outs during their lifespan (RICS, 2016), so this roughly translates into an average life-cycle waste generation of 220 t per 100 m$^2$ of floor area.

![Figure 2.2: Shearing layers of a building (Brand, 1994).](image)

The execution of fit-outs is more frequent in non-residential buildings, which represent 26% of the total floor area in the European Union building stock. Non-residential buildings are broken down into retail (7%), offices (6%), education (4%), industrial and sport facilities (4%), hotels and restaurants (3%), and healthcare (2%) (Economidou, 2011). In accordance
with this, non-residential buildings in the UK account for 28% of the building stock monetary value (PIA, 2015). Although a minority of the building stock, it is estimated that 11% of the UK construction expenditure is invested on non-residential fit-outs (RICS, 2016).

Tucker and Treloar (1994) estimate the replacement rate for a fit-out to be once in seven years. In a more recent study, Roussac et al. (2008) report a 10-year fit-out cycle, based on a property management portfolio. Divergently, the duration of a major refurbishment cycle for office buildings, which involves elements such as the building envelope, is estimated to be 25-30 years (Rey, 2004). Rossi and Deepak (2009) affirm that retail fit-outs have a short replacement rate of typically 2-10 years and they propose that a whole life-cycle methodology can support the decision-making process to reduce emissions in fit-outs. The authors state that to minimise the cost impact of replacement cycles, it is prudent to ensure that the design life of finishes is close to the length of the replacement cycle.

Forsythe and Wilkinson (2015) quantify the number of refurbishments and related trends using building permit data from the Melbourne Central Business District over the period of 2006-2010 and found that almost 200 office fit-outs took place each year in the square kilometre of study, and that up to 70% of the floors in a high-rise office building will undergo refurbishment in a five-year period. In terms of location, they found that most fit-outs occur in prime areas of the district; in terms of age, most fit-outs take place in younger stock. Wilkinson and Remoy (2011) also find that adaptations to office buildings are largely focussed on the superior-quality office, while there is less activity in the lower-quality stock.

Fit-outs that result in higher energy efficiency (Urge-Vorsatz et al., 2007) and occupant comfort\(^2\) (Barlow and Fiala, 2007) are crucial to improving existing constructions, which represent the vast majority of the future building stock (Barlow and Fiala, 2007). Kelly (2009) states that 87% of buildings in the UK in 2050 are already built, as the replacement rate by new construction is only 1-3% per year (Barlow and Fiala, 2007; Roberts, 2008). In the same order of ideas, Moe (2007) indicates that it will take approximately 65 years for a new energy-efficient building to recover the energy and resources lost in the demolition of an existing building. Likewise, Power (2008) shows that refurbishment is more effective than demolition on the basis of time, cost, community impact, sprawl prevention, reuse of existing infrastructure, and protection of existing communities.

2.3.2 Categories of building fit-out

The wide range of building products installed and removed in building fit-outs can be introduced by briefly describing the two fit-out categories. Building fit-out projects are generally split into category A, white canvas fit-out, and category B, bespoke fit-out. Figure 2.3 shows an example of these two types of fit-out as well as the “shell and core” stage (completed outer building framework), which is the stage preceding any fit-out project. The three fit-out stages are defined next.

\(^2\) Occupant comfort and well-being can be improved by providing a pollutant-free environment, as well as acoustic, thermal and visual comfort.
Figure 2.3: Different categories of building fit-outs: (a) shell and core (precedent to fit-out), (b) category A (white canvas), and (c) category B (bespoke fit-out) (O’Leary, 2014).

**Shell and core**

This is the stage preceding any fit-out project. Shell and core (Figure 2.3 a) entails the completed outer framework of a building, e.g. the concrete and metal frame of a weather-proofed space. From the outside the building appears to be complete, but the inside is a blank space with endless fit-out possibilities (O’Leary, 2014).

**Category A fit-out (Cat A)**

Category A works (Figure 2.3 b), or white canvas fit-out, extends central services onto floor plates and provides a background for Category B works. Cat A comprise services, life safety elements and basic fittings and finishes for the operation of lettable space, including (BCO, 2009):

- suspended ceilings,
- RAF,
- HVAC systems,
- open plan base lighting,
- life safety systems (fire alarms, sprinklers, emergency lighting),
- basic statutory signage,
- distribution boards,
- basic security system and wireway.

**Category B fit-out (Cat B)**

Category B works (Figure 2.3 c), or bespoke fit-out, is the stage when the space is refurbished according to the particular needs of the tenant, by installing all corresponding finishes, fittings, and furniture. Cat B may include (BCO, 2009; O’Leary, 2014):

- internal partitioning,
- additional floor and wall finishes,
• mechanical, electrical services and lighting upgrade,
• IT and telecommunications installations and distribution,
• enhanced toilet provision,
• adaptation of life safety systems,
• decoration and branding,
• fixtures and fittings,
• furniture,
• security installation enhancements,
• audio/visual installation,
• corporate and way finding signage,
• vertical transportation enhancements,
• staircase links between floors.

2.3.3 Sustainable interior building products

Interior design has traditionally concerned itself with the one-dimensional practice of providing aesthetic enhancements to an interior space for a client (Cargo, 2013). However, over the past 25 years interior design is shifting towards the agenda of also providing healthy and sustainable environments for occupants (Bonda and Sosnowchik, 2007). This is a crucial factor to consider since people normally spend more than 90% of their time indoors, and therefore indoor conditions have important implications for user health, well-being and performance (Frontczak and Wargocki, 2011).

The main measures taken to provide healthy and sustainable interior spaces are: designing adequate natural lighting, using energy-efficient lighting equipment with control systems, improving indoor air quality (avoiding the use of materials that emit pollutants and designing suitable ventilation), providing thermal, visual and acoustic comfort, designing flexible spaces (using modular, demountable and expandable walls, floorings, ceilings, partitions, and furniture), and selecting sustainable interior materials (Karsli, 2013).

There is no universal definition of sustainable building materials or components, but they are often regarded as products that cause no harm (or significantly low harm) to the environment, while offering specific benefits to the users in terms of maintenance, energy efficiency, occupant health and comfort, and the consequent increase of productivity (Ding, 2014). Correspondingly, sustainable building materials must be sustainable during their whole life-cycle, so they should be reusable, recyclable, or biodegradable and still have the right functionality at affordable price. These materials can be made from natural renewable sources or using technical nutrients that are properly recyclable.

Conversely, there are some materials that should be avoided to the greatest possible extent, such as antimony trioxide, asbestos, benzene, cadmium, chromium, mercury, lead and PVC, which were assembled by the International Agency for Research on Cancer (IARC) and Germany’s Maximum Workplace Concentration (MAK) (McDonough and Braungart, 1994). Another type of product that should be avoided are what McDonough and Braungart (1994) call “monstrous hybrids”, which are products with mixtures of materials, both technical and biological, that make it extremely difficult or impossible to salvage them at the end of their useful life.
Regardless of the benefits that sustainable building materials and components may offer, some studies have found that trends and fashion are considered the most important factors in the product selection process (Usal, 2012), followed by durability and maintenance (Moussatche, 2002). Additionally, this latter research confirms previous studies showing that fast and easy access to data on sustainable products is an important factor in the selection process (Guerin and Ginthner, 1999, as cited in Moussatche, 2002).

Accordingly, the lack of information on the availability and specifications of sustainable building products is an important barrier preventing their more widespread use. Different institutions from around the globe are introducing initiatives to help overcome this problem. In 2003, the European Commission (2003) released the Integrated Product Policy (IPP) to identify products within the construction sector that have the greatest life-cycle environmental impact potential. The IPP has led to the development of environmental product declarations (EPDs) to communicate the environmental performance of materials from a life-cycle perspective (European Commission, 2003). The EPD is being recognised by some assessment methods and its increasing use is being encouraged by the European Union (Ding, 2014). Likewise, the European Union regulation concerning the registration, evaluation, authorisation and restriction of chemicals (REACH) came into force in 2007 and replaces several European directives and regulations with a single system (HSE, 2016).

The EU Ecolabel (2019) is Europe’s and the UK’s official environmental label, managed by the European Commission (Commission Regulation, 2010). It is a voluntary label of environmental excellence that is awarded to products and services meeting high environmental standards throughout their life-cycle (EU Ecolabel, 2019). Established in 1992, it promotes the circular economy by encouraging producers to generate less waste and carbon emissions during the manufacturing process (European Commission, 2019c). The EU Ecolabel criteria also encourages companies to develop products that are durable, easy to repair and recycle. The corresponding logo can be found on the packaging of every EU Ecolabel product (European Commission, 2019c).

The Cradle to Cradle certification is a third-party sustainability label implemented in 2005 (Arche Consulting, 2020) to assess the environmental and social performance of products across five critical sustainability categories: material health, material reuse, renewable energy and carbon management, water stewardship, and social fairness. A product can be rated with an achievement level of Basic, Bronze, Silver, Gold, or Platinum for each category (C2Ccertified, 2020).

With the aim of providing a platform to seek and exchange sustainable materials and components, the US Business Council for Sustainable Development launched in 2013 an online tool called Marketplaces for Materials that allows businesses to shop for building products in a format not dissimilar to finding apartment listings on Airbnb (USBCSD, 2019). The Quartz Project (2019) is an open database of composition, health hazard and environmental impact data for building products, led by Flux in collaboration with Google and other companies. Similarly, the UK initiative Ongreening (2019) provides an online open-access database of some sustainable building components and projects.
Two examples of sustainable building components that are commercially available are Interface flooring (Interface, 2019) and Armstrong ceilings (Armstrong, 2019), which are both made from recycled materials, are easy to install and disassemble, and some of their products can be taken back by the manufacturer and recycled at the end of their useful life, as their constituent materials are easy to separate. In addition, Interface has developed heterogeneous nature patterns in their carpet tile arrangements, allowing the replacement of a single tile without compromising aesthetics.

Companies such as Flute (2019) and ECOR (2019) use mixed waste fibres and apply pressure and heat to create high performance sheet boards similar to MDF, with applications in office spaces such as cabinetry, furniture, walls and ceiling panels. Similarly, ARUP is using residual waste from plants to create biocomposite materials useful for cladding or partitioning that can be composted at the end of life (Carra, personal interview, 27 November 2015). Clayworks (2019) manufactures a blend of natural clay plaster for interior design that presents one of the lowest embodied energies out of any interior finishes. It is easy to repair, and does not require an extra layer of paint. Cross-laminated timber (CLT) is an engineered wood product gaining popularity as it presents relatively low environmental impacts and can be used for structural purposes and for interior cladding (Rose, 2016). Besides, CLT can be manufactured using recycled (secondary) timber as feedstock (Rose et al., 2018). Finally, emerging technology such as 3D printing shows a great potential to create building materials and components, using biodegradable or recyclable technical nutrients (EMF, 2015a; 2015b).

2.3.4 Building in layers and designing for deconstruction

The advance of technology in the construction sector (including 3D printing) is increasingly allowing to construct, adapt and deconstruct buildings using different approaches. The concepts of building in layers and designing for deconstruction (DfD) both relate to the adaptability of a built space, considering that buildings are constantly changing over time, adapting to the rotating needs of tenants (Habraken, 1972; Brand, 1994).

Building in layers

Habraken’s work (Habraken, 1972) is considered as the starting point of the concept of “open building” (Cheshire, 2016), which other authors, such as Brand (1994), have built upon. Open building is an approach to the design of buildings that takes account of the possible need to change or adapt the building during its lifetime, according to economic, social or technical change (WikiMili, 2019).

The concept of open building relies on the idea that the built environment is made up of different hierarchical levels (specific spheres of control), in which higher levels serve as the setting and context in which lower levels operate (Habraken, 1998), and the change at lower levels generally emerges faster than at upper levels (Zeiler et al., 2009).

Higher-level layers in the built environment include “city structure” and “urban tissue”, which contain lower-level layers, such as the “support” and the “infill” (Zeiler et al., 2009).

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3 Biocomposite is a compound material formed by a natural resin and a reinforcement of natural fibres (Avérous and Le Digabel, 2006).
The support layer, also known as “base building”, normally includes the building’s primary structure, the building envelope (e.g. roof and facade), and public circulation and fire exits, as well as primary mechanical and supply systems (DBW, 2019). The infill layer, also known as fit-out (Cheshire, 2016), includes the physical products and spaces controlled by the individual occupants to make habitable space in a base building (WikiMili, 2019).

Open building aligns with the concept of “building in layers”, which means the interfaces between different building layers should be designed to allow each layer or system to be modified or replaced without adversely affecting the other layers (Cheshire, 2016). For instance, the fit-out layer can change without forcing the base building to change (WikiMili, 2019), and there could be some level of redundancy in the base building to allow for future adaptation; e.g. ceiling heights that can accommodate office, retail or residential space (Cheshire, 2016).

**Designing for deconstruction**

Design for deconstruction/disassembly (DfD) is the design of buildings to facilitate future change and the eventual dismantlement (in part or whole) for recovery of systems, materials and components (Guy and Ciarimboli, 2006). Cruz et al. (2015) state that DfD can yield significant economic benefits and stimulate the creation of a brand-new market for salvaged construction materials. However, designing building products for easy deconstruction does not ensure their actual reuse when removed (Rose and Stegemann, 2018a).

Evidently, reusing of materials and components is regarded as a more sustainable option than recycling. Designing for reuse and designing for recycling are not interchangeable because the former requires that materials and components are able to be removed intact, maintaining services and aesthetic qualities. Conversely, designing for recycling may entail destructive disassembly processes as the materials and components removed will be further processed into new materials (Morgan and Stevenson, 2005).

There are different barriers to DfD but many authors coincide that the main obstacle is the time to deconstruct, followed by low landfill disposal costs, disintegration of the supply chain, and low demand of disassembled materials (Morgan and Stevenson, 2005; Guy and Ciarimboli, 2006).

On the other hand, some of the key principles to DfD are: using materials and systems that are modular to facilitate their reuse and designing connections and systems that are easy to separate. Morgan and Stevenson (2005) present the major structure systems related to deconstruction: masonry, light frame, panel system, and post & beam; as well as the common connection types: screw, bolt, nail, friction, mortar, adhesives, and rivet. Table 2.1 shows the advantages and disadvantages for these connection types.

An example of an interior building product which is easy to deconstruct and adapt is the modular shelving system Vitsœ 606 (2019), which has maintained the same design since 1960, when it was first created. Inspired by this concept, there are now several modular shelving systems commercially available.
DIRTT (2017) Environmental Solutions is an interior design company that customises pre-fabricated building components that assemble by using a kind of zipper and zip-locks, allowing easy installation and removal of components. As well, all boards and tiles are bar-coded, which allows them to be traced and taken back to the manufacturer at end of life (McCagherty, personal interview, 12 September 2016).

Table 2.1: Types of connections in constructions and their respective advantages and disadvantages (Morgan and Stevenson, 2005).

<table>
<thead>
<tr>
<th>Type of connection</th>
<th>Advantage</th>
<th>Disadvantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Screw</td>
<td>easily removable</td>
<td>limited reuse of both hole and screws; cost</td>
</tr>
<tr>
<td>Bolt</td>
<td>strong; can be reused several times</td>
<td>can seize up making removal difficult; cost</td>
</tr>
<tr>
<td>Nail</td>
<td>speed of construction; cost</td>
<td>removal usually destroys a key area of element</td>
</tr>
<tr>
<td>Friction</td>
<td>keeps construction element whole during removal</td>
<td>undeveloped type of connection; structurally weaker</td>
</tr>
<tr>
<td>Mortar</td>
<td>can be made to a variety of strengths</td>
<td>mostly cannot be reused; difficult to separate bonded layers</td>
</tr>
<tr>
<td>Adhesives</td>
<td>strong and efficient; deal with awkward joints; variety of strengths</td>
<td>practically impossible to separate bonded layers; cannot be easily recycled or reused</td>
</tr>
<tr>
<td>Rivet</td>
<td>speed of construction</td>
<td>difficult to remove without destroying a key area of element</td>
</tr>
</tbody>
</table>

2.3.5 Closed-loop supply chains

The supply chain or value chain is an important element to consider when thinking of circular fit-outs (or circularity in any economic activity). Closed-loop supply chains (CLSCs) are those with reverse flows of used products back to manufacturers (Souza, 2013). The manufacturers may remanufacture or recycle the post-consumer product as a whole or in parts. This cyclical flow aims to ensure that products and materials remain useful at their end of life, therefore avoiding resource consumption and waste generation. As well, reusing and recycling products and materials may yield substantial economic savings (McDonough and Braungart, 1994).

By 2035, looping of materials through “reverse logistics” could be increased by 15% by mass, resulting in 30% material cost saving, adding 5% additional labour cost and saving €100-130 million annually, according to scenario modelling (EMF, 2015b). Reverse logistics is the process of moving goods from their typical end-of-life destination to concentrate them at a certain location for the purpose of capturing value through reuse, remanufacture, parts harvesting or recycling (WEF, 2015).

A common mechanism for reverse logistics is a “take-back scheme”, also known as take-back program, which is a service organized by a manufacturer or retailer for collecting used products or materials from consumers and re-introduce them into the original processing or manufacturing cycle (CEPG, 2019). Usually, manufacturers or retailers collect only their own
products, and not those from other companies (Shears, personal interview, 27 September 2016).

Office equipment manufacturer, Xerox, was one of the first companies to introduce product take-back schemes. The company reported annual savings of several hundred million US dollars due to remanufacturing and reuse of equipment and parts while diverting more than fifty thousand tonnes of material from the waste stream (Fleischmann, 2000). Companies that have introduced take-back schemes in the built environment include Armstrong (2019) for ceilings tiles, Forbo (2019), Interface (2019) and Tarkett (2019) for carpet tiles, resilient flooring and other floor finishes, and British Gypsum (2019) and Knauf (2019) for plasterboard and gypsum-based materials.

Take-back schemes are encouraged by the concept of extended producer responsibility (EPR), which holds manufacturers physically and financially responsible for taking back used products at the end of their useful life. The concept of EPR was formally introduced in Sweden by Lindhqvist and Lidgren (1990), and it is defined by the OECD (2001) as “an environmental policy approach in which a producer’s responsibility for a product is extended to the post-consumer stage of the product’s life-cycle”. EPR legislation can take the form of individual producer responsibility (IPR) or collective producer responsibility (CPR). CPR mutualises responsibilities of many different individual producers, and it is more common than IPR in Europe (European Commission and DG Environment, 2014).

Plambeck and Wang (2009) show that IPR legislation results in manufacturers designing products with higher recyclability. Atasu and Subramanian (2012) and Esenduran and Kemahlioglu-Ziya (2014) demonstrate that IPR results in greener products (more easily recyclable) than CPR. However, CPR may provide better operational cost efficiency due to the impact of economies of scale in recycling costs.

CLSCs literature published before the 1990s, typically assumed that product returns were uncontrollable. Thierry et al. (1995) publish one of the first papers to describe the concept of “product recovery management”. Later on, Guide and Van Wassenhove (2001) rename this concept as “product acquisition management” and state that the manufacturer can control the timing, quantity and quality of product returns and be profitable in some cases.

Generally, in CLSCs there are three main parties: the manufacturer (who produces the product), the retailer (who sells the product), and the client (who buys the product), but there can also be extra parties involved in the supply chain. The collection of used products can either be performed by the manufacturer, the retailer or a third party. Likewise, the remanufacturing can be carried out by the original manufacturer or by a third party. Savaskan et al. (2004) analyse whether the retailer or the manufacturer should collect returned products under monopoly and competitive situations. It was concluded that the manufacturer can benefit from remanufacturing and should therefore align the incentives for this purpose. Additionally, the retailer is the agent who is closer to the customer and can be the most effective pursuer of product collection for the manufacturer.
When third parties are involved, the process is referred to as a decentralised CLSC. Guide and Van Wassenhove (2009) state that time-sensitive products, like computers, require a decentralised CLSC, while products with low time sensitivity, such as power tools, are best served by a centralised CLSC. Toktay and Wei (2011) show that decentralisation without the proper incentives may be inefficient, and they develop cost-allocation mechanisms to coordinate the manufacturing and remanufacturing operations of one particular company.

Rotor DC (2019) is an example of a third-party post-consumer collector in the construction industry. They actively look for large building compounds scheduled for renovation or demolition and set up partnerships with the owners and demolition companies to salvage components such as doors, windows, lowered ceilings or lighting devices and sell them to new clients. Most of these components get sold before dismantling as an inventory of the available materials is made and sent to potential clients, reducing in this way the cost of stocking.

Guide and Van Wassenhove (2009) present the evolution of CLSCs over the previous years and state that key drivers for CLSC design are the volume of returns, the marginal value of time, and the quality of returned products. Vachon and Klassen (2010) point out the need for more empirical research, particularly on documenting acquisition, collection and remanufacturing costs, and on the overall market for remanufactured products. Souza (2013) presents a review on CLSCs and mentions three possible take-back strategies: trade-in programs, leasing, and relicensing fees. He also indicates the need for more research in the subject. Agrawal et al. (2012) find that the profitability and environmental impact of leasing relative to selling depends on the product durability and the environmental footprint of the product during the use stage.

**Information systems that support CLSCs**

The use of information systems in production-planning and product-control techniques make management of these activities more predictable (Guide et al., 2000). Ness et al. (2014) describe how radio frequency identification (RFID) technology coupled with BIM may enable a database of components and assemblies which can be imported into virtual models for new buildings at the design stage.

The “characterisation” of installed building components is a key element for CLSCs in the built environment (Rose and Stegemann, 2018b). A type of product identifier that is gaining increasing popularity is the “material passport”, also known as product passport, which is a set of data to describe the characteristics of materials, components or products. The aim of this type of identifiers is to facilitate recovery or reuse at end of life for maintaining the value of products overtime, as well as incentivising manufacturers to produce circular products (BAMB, 2018; EPEA, 2018). For instance, materials and components found at a site to be demolished or deconstructed, can be identified and characterised to ensure their highest possible usefulness after the site has been demolished. Although material passports can potentially improve the circularity of products’ life-cycle, there is no standardisation for them yet.

The “internet of things” (IoT) has the potential to provide a platform for tracking building components as “intelligent assets”. IoT is the networked connection of physical objects which can exchange information through the Internet. These physical objects are called intelligent assets as they can sense, record and communicate information about themselves.
and/or their surroundings. This definition also includes assets that are not continuously transmitting information and things that do not feature wireless communication (WEF, 2015).

### 2.3.6 Circular business models

New business models are necessary to support closing the loop in supply chains, such as the leasing or the remanufacture model (EMF, 2015b). An example of the leasing model is Philips’s “pay per lux”, which provides the opportunity to buy the “service of light” rather than buying lighting devices, helping occupants to plan their lighting requirements and consumption more wisely while encouraging lighting manufacturers to produce longer lasting and more efficient devices. At the end of life, Philips (2019) lighting products are taken back into the production process, thus reducing waste and optimising raw material use (Rau, 2015).

An example of the remanufacture model is Desko, which sells office furniture and then buys it back from clients at a lower price. After remanufacturing, this Dutch company sells the furniture again to a new client, repeating the cycle up to three times. In this way the furniture’s lifespan is expanded, providing more income for the same amount of production and benefiting customers interested in more affordable second-hand furniture (Circular Economy, 2015).

Premier Sustain (2019) is a British company that offers remanufacturing services to help their clients make the most of their existing office furniture assets. Their services include repair, re-upholstery, re-spraying, and cleaning, among other. They claim to have remanufactured over 7,000 items of furniture for clients including BBC Worldwide, Transport for London (TfL) and 10 Downing Street.

Community Wood Recycling (2019) is an organisation that goes to construction sites to collect end-of-life wood, categorise it and use the better-quality wood for making furniture, while lower-quality wood (including particleboard) is chopped and used for energy recovery. Besides their environmental agenda, this British company also pursues social benefits as they employ and upskill people from all backgrounds (Green, personal interview, 20 July 2016).

**Reuse third parties**

A “reuse third party” is defined for this work as a supply-chain actor which support the reuse or repurposing of building products in construction or refurbishment projects. An example of a reuse third party is Rotor DC (2019) (as mentioned earlier in subsection 2.3.5), which dismantles building products from refurbishment or demolition projects and then sells them to clients for reusing in new building projects. The Belgian company salvaged 400 tonnes of building products in 2015, which is a substantial figure considering that most components are relatively lightweight (compared to bricks for example) (Baker-Brown, 2017). To ascertain the price, they assign the top limit as 50% of the original price (when it can be found), while the bottom limit relates to the money they invested in finding and salvaging the item (Baker-Brown, 2017).

Similarly, Repurpose (2019) is a Dutch company which identifies reusable products within a building project to suggest reuse or repurposing options within the same project or in other
building projects. Repurpose offers clients the option to dismantle and handle the building components to be salvaged or provides guidance for this process.

**Reuse platforms**

In this work a “reuse platform” is defined as an online platform to connect supply with demand of end-of-life products, otherwise normally discarded. In this way, people, businesses or institutions (Contributors) who want to get rid of products they no longer want can list these items on the platform, and recipients (Re-users) can look for free second-hand products. Reuse platforms provide free stuff for Re-users and generally present a cheaper alternative than disposal for Contributors. Salvaged items in reuse platforms displace the consumption and production of new products, saving carbon emissions and reducing waste generation. Examples of reuse platforms in the UK include Globechain (2019), Warpit (2019) and Reyooz (2019), which are London-based and were contacted in this study.

Globechain (2019) was founded in 2015 and it has linked thousands of clients, including the National Health Service (NHS), who want to donate or obtain second-hand items. This website lists all sorts of products, but most of the listed items comprise furniture and interior building components. The platform is available to anyone and free to register; there is a fee of £10 per listing, which can include up to 100 items of the same category (e.g. 100 chairs), and it also provides the option of an annual membership fee for large organisations and a one-off fee for bespoke projects (Al-Karooni, personal interview, 10 May 2016). Globechain was closely involved in one of the fit-out case studies analysed in this work, which shifted this actor to being a reuse third party, instead of a reuse platform, as later detailed in subsection 4.4.6 and discussed in subsection 5.2.1.

Warpit (2019) is another “resource redistribution network”, and since 2011 this seven-member-staff platform connects businesses and organisations, rather than individuals, for sharing and reusing products. Items listed here include mostly furniture, office consumables (e.g. stationary or ink cartridges) and lab equipment. Charities are free to register, while the subscription fee for schools is £50 per year, and for businesses this fee ranges from £195 to £358 per month, depending on the size of the company (i.e. number of employees) (O’Connor, personal communication, 05 December 2017).

Reyooz (2019) was first launched in 2014 and started operating since 2017. This platform is run by two staff members and connects businesses and organisations who want to share office furniture and equipment. Unlike the two reuse platforms previously mentioned, the collection process for salvaged items is organised by Reyooz, through sub-contracted carriers. The collection cost is charged to the Contributor and it is normally cheaper than the disposal cost would be for that item. Reyooz has partnered with a waste-management company, Bywaters (2019), and together they estimate collection costs. Listed items that could not be salvaged are taken to Bywaters for recycling, incurring in disposal charges (Dick, personal communication, 04 December 2017). Both Warpit and Reyooz platforms are currently used in refurbishment projects at UCL, as later detailed in section 4.5.

The operating process is similar for these reuse platforms and is described as follows:

1. Contributor list the item(s) on the platform’s website;
2. potential Re-users request the item and Contributor can chose whom to give the item to;
3. the collection process is agreed between the parties, but generally the Re-user either collects the item or pays the shipping cost.

In the case of Reyooz, the operating process is slightly different as they take care of the shipping and they choose the Re-user based on shipping costs and distance. For the case of Globechain, Re-users are asked to fill in a feedback form every third collection to gather socio-economic and environmental data.

2.4 Overview of waste management

2.4.1 Construction and demolition waste

C&D waste “is a waste stream that is primarily received from construction sites. Some examples of C&D waste include, but are not limited to, concrete, rebar, wood, panelling, linoleum, and carpet” (DEFRA, 2015).

In the UK, the construction industry consumed more than 380 million tonnes of resources annually (BRE, 2008), and C&D waste accounted for 32% of the annual waste generation, followed by mining and quarrying (29%), industrial and commercial (19%) and household waste (12%) (DEFRA, 2020).

It is relatively difficult to precisely quantify C&D waste arisings, and figures for the UK in grey literature vary among each other. Moreover, some sources consider only C&D waste, while other sources aggregate CD&E waste.

A survey was conducted in England (Office of the Deputy Prime Minister, 2004) and reports 90.93 Mt of CD&E in 2003, where only aggregates and soils were considered. CRW (2010) provided limited data based on case studies recorded in the SmartWaste tool (presented in subsection 2.5.1), although the case-study sample is not large enough to draw robust statistical inferences. Based on secondary data, Deloitte (2015) provides the figure of 100.23 Mt of CD&E generation in 2012.

A report by WRAP (2010) quantified the C&D waste arisings in England in 2008. The inert fraction of C&D waste was estimated using surveys, while the non-inert fraction was calculated based on data provided by waste handlers to the Environment Agency. A total C&D waste generation of 86.93 Mt was reported for 2008. This report pays particular attention to non-inert C&D waste (wood, plastics, metals, etc.), but it provides limited data on the material composition of C&D waste.

The latest issue of UK Statistics on Waste (DEFRA, 2020) provides a figure of 66.2 Mt for C&D waste in 2016, which is lower than that reported by WRAP (2010), despite the figure in the latter report is given for 2008. In the same report, DEFRA (2020) provides a figure of 136.2 Mt for CD&E waste (including excavation) for 2016. These estimations are mainly derived from waste returns by transfer sites, treatment facilities, and landfill operators in compliance with the Environment Agency.

In terms of waste composition, WRAP (2010) provides a breakdown of material composition
for C&D waste in England in 2008, as shown in Table 2.2. A study conducted by Rose (2019)
considered four case studies – two refurbishment and two new build projects – and reported
the average material composition of waste arisings, based on data provided by Waste Con-
tractors.

Table 2.2: Share (by mass) of each waste stream generated in England (WRAP, 2010) and averaged from four
case studies (Rose, 2019).

<table>
<thead>
<tr>
<th>Waste stream</th>
<th>WRAP, 2010 (Share by mass)</th>
<th>Rose, 2019 (Share by mass)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asbestos/insulation</td>
<td>0.7%</td>
<td>0.7%</td>
</tr>
<tr>
<td>Asphalt</td>
<td>0.9%</td>
<td></td>
</tr>
<tr>
<td>Concrete (only)</td>
<td>-</td>
<td>19.3%</td>
</tr>
<tr>
<td>Glass</td>
<td>-</td>
<td>0.7%</td>
</tr>
<tr>
<td>Gypsum</td>
<td>0.7%</td>
<td>0.9%</td>
</tr>
<tr>
<td>Hardcore</td>
<td>37.1%</td>
<td>41.9%</td>
</tr>
<tr>
<td>Metals</td>
<td>1.8%</td>
<td>2.3%</td>
</tr>
<tr>
<td>Mixed packaging</td>
<td>-</td>
<td>2.7%</td>
</tr>
<tr>
<td>Mixed waste</td>
<td>11.4%</td>
<td>3.9%</td>
</tr>
<tr>
<td>Plastic</td>
<td>0.2%</td>
<td>1.2%</td>
</tr>
<tr>
<td>Soils</td>
<td>44.5%</td>
<td></td>
</tr>
<tr>
<td>Soils and stones</td>
<td>-</td>
<td>18.8%</td>
</tr>
<tr>
<td>Undefined</td>
<td>-</td>
<td>1.8%</td>
</tr>
<tr>
<td>Wood</td>
<td>2.7%</td>
<td>6.0%</td>
</tr>
</tbody>
</table>

Below 70% of the C&D waste generated in the UK is treated (Eurostat, 2019b), and the
recovery rate (including recycling) of treated C&D waste is above 90% (TCS, 2013; Euro-
stat, 2019a; DEFRA, 2020), which is higher than the average in the European Union⁴. How-
ever, less than 1% of recovered materials are reused (EMF, 2015b), and only 20% of the
total aggregates used for producing building materials come from recycled sources (TCS,
2013), rupturing the resource circularity in this practice. In fact, most recycling in any pro-
ductive sector is actually “downcycling”⁵, which means that quality of materials is impover-
ished over time as it is not yet possible to maintain the value when recycling materials not
originally designed for this practice (McDonough and Braungart, 1994). In line with this, an
important share (around 17%) or recovered C&D waste is spread at exempt sites (UK Gov-
ernment, 2011), e.g. used for land modelling during construction projects (Lawson et al.,
2001), and above 20% is used for landfill capping (UK Government, 2011).

In Europe, material recycling and waste-based energy recovery captures only 5% of the orig-
inal raw material value (EMF, 2015c), although the elimination of the extracting and pro-
cessing of raw materials can potentially save up to 75% of embodied energy and associated

⁴ The average C&D waste recycling rate for the European Union is just below 50% (European
Commission, 2014a).
⁵ Contrary to downcycling, upcycling refers to recycling processes where the quality, durability, and
economic value of materials are maintained or improved (Chini, 2007).
These statistics show a significant scope for C&D waste reduction and for more efficient recovery of C&D waste in the UK and Europe, through higher rates of reuse and high-quality recycling. Waste management plays a crucial role in this agenda, and it relies on the definition of waste (Cheyne, 2002; Pongrácz and Pohjola, 2004), as explained in the next subsections.

2.4.2 Definition of waste

The legal definition of waste in the UK derives from the European Union Waste Framework Directive (WFD) (Sustainability Exchange, 2019), which was originally adopted in 1975 as Council Directive 75/442/EEC (1975) with the aim of ensuring the safe disposal of waste (DEFRA, 2012). The latest legal definition of waste in Europe and the UK remains essentially the same since then and can be found in the current WFD (Council Directive 2008/98/EC, 2008), which states that waste comprises “any substance or object which the holder discards or intends or is required to discard”.

The use of the term “discard” instead of “dispose of” in the WFD has the purpose to include the widest possible acts of abandonment of things (Pongrácz and Pohjola, 2004). A substance or object may be discarded for a range of reasons: it may be intentional or accidental, voluntary or mandatory, and it may even occur without the holder’s realising it (DEFRA, 2012). In line with this, discarding also covers activities such as recycling and other recovery operations (DEFRA, 2012; UK Government, 2016a). Even if the substance or article is given to someone else to be reused, it is still legally considered to be waste (Sustainability Exchange, 2019a), unless it is tested, and it complies with specific criteria (as detailed below).

Waste can also be viewed as an “abandonment or transfer of ownership”, where ownership over something can be defined as a right and a responsibility to act on it (Pongrácz and Pohjola, 2004). So, by disposing of things, the corresponding actors are in fact ceding ownership and responsibility over that object or substance.

The label “waste” does not necessarily mean that the thing is an ultimate waste; rather, it means that it will be treated as waste (Pongrácz and Pohjola, 2004), so it must be handled under the relevant regulations. Under the present European definition of waste, recoverable material is seen more as a potential pollutant than as a potential raw material (Bontoux and Leone, 1997, as cited in Pongrácz and Pohjola, 2004). However, waste is in fact increasingly seen as resource-rich material or “non-waste” (Pongrácz and Pohjola, 2004).

According to the WFD, waste ceases to be waste and becomes non-waste when it “has undergone a recovery operation, including recycling, and complies with specific criteria”. Namely, the substance or object must a) be commonly used for specific purposes; b) have a market or demand for it; c) fulfil the existing legislation and standards applicable to products of its kind; and d) not lead to adverse environmental or human health impacts. There are specific tests that must be met to ensure that a waste has achieved “end of waste” (UK Government, 2016a). The European Union end-of-waste regulations and criteria are still being developed for priority waste streams (European Commission, 2019b).
Waste classification
Most of the taxonomies classify wastes either by their characteristics or by their origin (Pongrácz and Pohjola, 2004). Based on their characteristics, wastes can be classified into hazardous, stable non-reactive hazardous waste (SNRHW), non-hazardous, and inert (EA, 2010; UK Government, 2016b). Landfills for hazardous waste can only accept this type of waste. SNRHW can be sent to landfill for non-hazardous waste, but it must go into a separate cell that is not used for the deposit of biodegradable wastes. A landfill site for non-hazardous waste can accept municipal waste along with non-hazardous wastes of any other origin, including inert wastes. Inert waste is that one which will not dissolve, burn or otherwise physically or chemically react, biodegrade or adversely affect the environmental or human health (EA, 2010).

Wastes split by origin or source include household waste, commercial and industrial (C&I) waste, CD&E waste, and other waste (DEFRA, 2020). The European Waste Catalogue (EWC), legally known in the UK as List of Wastes (LoW) (UK Government, 2018), is a hierarchical list of waste descriptions established by Commission Decision 2000/532/EC (2000). The EWC or LoW is divided into 20 chapters based on the origin of waste, from exploration, mining and quarrying to municipal wastes. Individual wastes within each chapter are assigned a six-figure code, where the first two digits relate to the chapter that includes the corresponding waste.

Yet, another classification of waste is provided by Pongrácz and Pohjola (2004), where waste is divided into four classes, based on the state of its “utility”. Class 1 includes non-wanted things with no purpose; class 2 comprises things that were given a finite purpose and thus destined to become useless after fulfilling it; class 3 includes things with well-defined purpose, but their performance ceased being acceptable; and class 4 considers things with well-defined purpose, and acceptable performance, but their users failed to use them for the intended purpose.

2.4.3 Definition of waste management
According to the WFD, “waste management shall mean collection, transport, recovery and disposal of waste, including the supervision of such operations and after-care of disposal sites”. Waste management in European Union law is regulated by and increasingly complex network of legislation at both Community and national level (Cheyne, 2002).

The goal of waste management is to protect public health and the environment, and so far it has had a positive impact (Pongrácz and Pohjola, 2004). However, waste management should shift towards also conserving resources through turning wastes into non-wastes, instead of only setting fixed targets for recovery or recycling (Pongrácz and Pohjola, 2004; Rose and Stegemann, 2018a). Therefore, effective waste management greatly relies upon the definition of waste (Cheyne, 2002). For instance, waste collected for recovering purposes should be defined as (non-waste) secondary raw material (Jacobs, 1997, as cited in Pongrácz and Pohjola, 2004), without the need of testing, and it should be excluded from waste restrictions that hinder resource conservation (Pongrácz and Pohjola, 2004).

In line with this, waste management is normally involved with the disposal stage of products,
although the waste-management system should also be engaged with the design stage (Pongrácz and Pohjola, 2004), considering that around 80% of a product’s environmental impact is determined by decisions made at the design stage (ECI, 2005). This would support designing products according to the planned end-of-life pathways, with the aim of protecting the environment and human health while also encouraging resource conservation. For instance, if a product may undergo material recovery, then materials that are the most economical to recycle should be used; on the other hand, if incineration is planned, it is sensible to omit chemicals that may lead to toxic emissions (Pongrácz and Pohjola, 2004).

### 2.4.4 Waste management hierarchy

A core element in a circular economy is the waste management hierarchy (Figure 2.4). From a (standard) WFD approach the most preferred option within this hierarchy is to reduce (lowering the amount of material consumed or waste produced), followed by reuse (using products repeatedly), recycle (using materials to make new products), recovery (for purposes such as composting or to obtain energy from waste (EfW)), and finally landfill (safe disposal of waste to landfill). From a circular economy approach the most favourable option is also to reduce, followed by retain in-situ (leaving products or components just where they are), reuse (either for the same or for alternative purposes), refurbish/remanufacture (returning a product to its original functional or aesthetic state), and finally recycle. Within the built environment, retaining, reusing and remanufacturing may involve maintenance or repairing activities. Reuse can either take place on site (in the same building) or off site (in a different project). Refurbish and remanufacture are considered synonyms in this work, and hence, only the term remanufacture is used in this context.

![Waste management hierarchy](author generated)

Maccarini and Avellanada (2013) propose a methodology to assess the potential of recyclability for building materials, based on a hierarchic upside-down pyramid, where the most favourable option is reuse, followed by recycle, infracycle, infrause, and finally landfill. These concepts are defined by the author as follows: recycle takes place when there is at least one chemical change of the material’s internal structure, maintaining its initial physical properties (e.g. recycling steel). Infracycle (synonym of downcycle) entails the same process with the exception that it decreases the material’s physical properties (e.g. recycling plastic). Reuse takes place when there are no chemical transformations of the material’s internal structure.
and the physical properties are maintained the same (e.g. reusing a wood beam), while infrasure entails impoverishment of the initial properties (e.g. crushed brick used as aggregate for new concrete).

### 2.4.5 End-of-life pathways

End-of-life pathways entail the final destinations of products or materials that have become waste – these include, among other uses, waste treatment operations such as recycling. A brief overview of end-of-life pathways is presented for all the waste generated in the UK, followed by an overview of specific C&D waste treatment.

Out of 277 million tonnes of waste generated annually in the UK, 77% is treated, while the rest is unaccounted for or lost into the environment (Eurostat, 2019b). The proportion of treated waste goes through different recovery treatments or other end-of-life pathways and destinations, as shown in Figure 2.5. Standard end-of-life destinations in the UK include recycling or other recovery alternatives (49%), landfilling (24%), and thermal treatments with or without energy recovery (DEFRA, 2020; Eurostat, 2019b).

![Figure 2.5: Waste treatment by percentage out of the total waste treated annually in the UK (DEFRA, 2020; Eurostat, 2019b).](image)

The corresponding data for C&D waste is less accurate, and it is taken from European-level databases. According to Eurostat (2019b), around 60 million tonnes of C&D waste were treated in the UK in 2016 (which is the latest available data). Out of this, 95% was reported to be recycled, 4% landfilled and 1% was used for backfilling (e.g. refill an excavated hole). Although a high recycling rate was reported, it is arguable whether uses such as land modelling should be considered recycling.

Landfilling in the UK typically involves lining and capping individual cells or compartments into which waste is compacted and covered to prevent the escape of polluting liquid or gases (DEFRA, 2011). Thermal treatment with energy recovery means the combustion of waste under controlled conditions in which heat is efficiently recovered for a beneficial purpose, such as steam or hot water for electricity generation or for industrial and domestic use. This includes, among other, EfW facilities and refused-derived fuel (RDF) (DEFRA, 2011).

Recycling is the reprocessing of the waste materials “for the original purpose or for other purposes, including organic recycling but excluding energy recovery” (DEFRA, 2012). Here,
a differentiation should be made between open-loop recycling and closed-loop recycling (Van Ewijk and Stegemann, 2016). Open-loop recycling is when “material from a product system is recycled in a different product system” and the inherent properties of material may be changed. On the other hand, closed-loop recycling takes place within the same product system while preserving the inherent properties of materials (ISO, 2006). Closed-loop recycling is often considered preferable to open-loop systems in terms of environmental impacts and economic benefits and considering that open-loop recycling runs the risk of downcycling, leading to a loss of technical and economic material value (Ligthart and Ansems, 2012; Spendelo, 2012, as cited in Geyer et al., 2016).

Both forms of recycling represent the outermost (and least preferable) end-of-life pathway in a circular waste management hierarchy, as seen in Figure 2.1 (EMF, 2015a). Other circular pathways include remanufacture and reuse (EMF, 2015a; 2015b; Geissdoerfer et al., 2017). These are all alternatives for turning waste into “non-waste” (Pongrácz and Pohjola, 2004).

Next to recycling, the preceding end-of-life cycle in a circular economy is the pathway of remanufacture (EMF 2015a), which is the process of returning a used product to at least its original performance, and it may involve dismantling the product, restoring and replacing components and testing the individual parts and/or whole product (TCRR, 2019a). Remanufacturing has a long history in the UK across the range of industrial sectors, mostly done by producers of durable manufactured assemblies, usually made of metal. The inherent value of the materials and the cost of production enable these products to be remanufactured to an as-new condition, saving material resources while making a profit (TCRR, 2019a).

Remanufacturing presents huge financial and environmental opportunities for the UK (APPSGR, 2014). Estimates suggest that the current value of remanufacturing activities in the UK is £2.4 billion (Chapman et al., 2010), with the potential to increase to £5.6 billion at the present time (Lavery et al., 2013, as cited in APPSGR, 2014). Closed-loop manufacturing systems are set to become an increasingly important aspect of the future manufacturing industry and a key component of the circular economy (TCRR, 2019b).

The innermost (and most preferable) end-of-life cycle in a circular economy is the pathway of reuse (EMF 2015a) and it means a material or product is used again for the same purpose as was originally intended (UK Government, 2016b). Examples of reuse include leasing items to be used several times by different people; roof tiles carefully removed from one building to be fitted onto another building’s roof; giving away items to “reuse networks” such as the Freecycle Network (2019) and Freegle (2019); and donating goods to charities or second-hand shops. In some instances, repairing and/or testing may be necessary when reusing products to ensure their proper functioning (WRAP, 2011).

Although there is generally little reuse of building components in the UK (Pilchner, personal interview, 29 June 2016), furniture reuse is particularly a well-established practice (WRAP, 2011). This has been partly facilitated through members of the Reuse Network (2019), previously known as Furniture Reuse Network (FRN), a national body co-ordinating 400 organisations for furniture and appliance reuse, such as charities (WRAP, 2011). Approximately 295,000 office chairs (3,500 tonnes) are reused in the UK every year, which represents
14% of all office chairs reaching the end of their life annually, saving over 35 kgCO₂eq per chair reused. Business, users and households benefit by more than £6m per year as a result of sales of second-hand chairs and through avoiding purchase of new ones (WRAP, 2011).

2.4.6 UK regulation on waste management
The Environment Agency (EA) is the main body in charge of the regulation on waste management in England. The EA is a non-departmental public institution, established in 1995 and sponsored by the United Kingdom government’s Department for Environment, Food and Rural Affairs (DEFRA), with responsibilities relating to the protection and enhancement of the environment in England and until 2013 also in Wales (EA, 2018).

The EA is in charge of granting the licenses to waste holders, who are all actors involved in the production, transportation or management of waste. Waste holders might be related to the production (waste producer), transportation (waste carrier), trading (waste dealer) of waste and also include companies handling waste on behalf of other companies (waste broker) (DEFRA, 2016). All waste holders are subject to the Waste Duty of Care Code of Practice and are required to conduct transactions only with actors holding an EA’s licence (DEFRA, 2016).

The EA also regulates the material inputs and outputs within material recovery facilities (MRFs), which are defined as regulated facilities that receive mixed waste to separate it into “Specified Output Material” for the purpose of selling it or transferring it to other facilities or persons, enabling material to be recycled or used by those facilities or persons (WRAP, 2014). The Specified Output Material is a batch of material (whether or not waste) that is: a) produced from a separating process of mixed waste; and b) it is made up of one of the following kinds of material in the largest proportion 1) glass, 2) metal, 3) paper, or 4) plastic (WRAP, 2014).

MRFs must report to the EA every three months the quantities of input and output materials as well as providing a sampling report on these materials. For input materials MRFs must take a sample for every 125 t they receive from each supplier. The sample must have a minimum mass of 10 kg for glass and metals, 50 kg for paper, and 20 kg for plastic. For output materials the sample must be 10 kg for every 50 t of glass produced, 10 kg for every 20 t of metals, 50 kg for every 60 t of paper, and 20 kg for every 20 t of plastic output (figures are given for 01 October 2016 onwards) (DEFRA, 2014).

MRFs are required to record the following information for each reporting period and keep it for at least four years from the date it was recorded: 1) the total mass in tonnes of mixed waste received by the MRF from each named supplier; 2) the mass and composition of each mixed waste material sample taken at the MRF from each named supplier; 3) the mass in tonnes of residual waste that leaves the MRF and where it is sent; 4) the mass in tonnes of mixed waste that leaves the MRF for separation at another MRF and where it is sent; 5) the total mass in tonnes of Specified Output Material that leaves the MRF and where it is sent; 6) the mass and composition of each Specified Output Material sample taken at the MRF; identified by the grade; and 7) details of the amount in tonnes of Specified Output Material produced by the MRF, identified by the grade (of glass, metal, paper and plastic) (DEFRA, 2014).
The Landfill Tax introduced in the UK in 1996 has the central purpose of ensuring that landfill costs reflect the full cost of the environmental impact of the activity. The implementation of this tax has encouraged business and consumers, in a cost effective and non-regulatory manner, to produce less waste, and to reuse or recover value from waste (Seely, 2009). There are two rates of Landfill Tax: the lower rate for inert waste (see definition in subsection 2.4.2) is £2.90 per tonne, while the standard rate is £91.35 per tonne (UK Government, 2019a), and both rates are increased around 3% yearly (UK Government, 2019b). Apart from this tax, a disposal fee per tonne must be paid which varies according to the landfill.

Until now, the Landfill Tax has “helped to push materials up the waste hierarchy by making other waste management systems more affordable”; however, the rising cost of landfilling may be conducive to increased fly-tipping (illegal surface dumping of waste), and it has also resulted in an increase of the next cheapest waste-management alternatives, such as incineration and export. Policies to re-insert landfill-diverted materials into the economy are now needed, such as taxation on incineration and EfW treatments (HCEAC, 2014). Although legislation is essential, the greatest gains occur through a well-informed, environmentally conscious public (Pongrácz and Pohjola, 2004).

2.4.7 Waste treatment infrastructure
Waste treatments such as recycling or energy recovery through incineration require the corresponding facilities to carry it out efficiently while minimising pollutants to the environment. The UK still relies on exporting a significant amount of its waste to be treated abroad, due to economic and infrastructural reasons.

The export of plastics and paper from the UK to China was a general trend but this is changing since 2018 due to China imposing more strict restrictions for the waste they take in (Qu et al., 2019). This means China now requires a much lower percentage of impurities for the incoming waste – e.g. 0.5% for paper, while the standard in Europe is 1.5% (Financial Times, 2018). However, the UK did not significantly reduce the amount of plastic and paper and cardboard waste imported. The waste streams that used to be sent to China before 2018, are now sent to other countries, such as Vietnam.

According to the Financial Times (2018) UK exported 342 kilotonnes of its plastic waste in the first half of 2017, almost half of this was mainly sent to China and Hong Kong. In the first half of 2018, UK exported 331 kilotonnes of this waste stream, with less than 10% sent to China and Hong Kong. The share of the remaining exports that used to be imported to China and Hong Kong was offset by other Asian countries, such as Malaysia. In the case of paper and cardboard, the UK exported 2,401 kilotonnes of this waste stream in the first half of 2017, and over 60% was sent to China alone. In the first half of 2018, UK exported 2,290 kilotonnes of this waste stream, and only around a third of this was imported to China, while India made up for most of the remaining share.

RDF, used for energy recovery through incineration, is also mainly exported abroad. In one of the MRFs visited during this study, it was found that RDF is baled and exported to Netherlands or Germany, since there is not adequate infrastructure for energy recovery in the UK.
With the imminent Brexit situation, it might become costlier to export waste to other European countries, and the UK may need to develop different plans.

### 2.4.8 Conventional procedure at a material recovery facility

In the UK, most C&D waste ends up at a MRF (Cheshire, 2016), where waste is segregated, and if applicable, cleaned, screened and graded before being sent to the corresponding recycling facility or final destination. MRFs normally have a space (often an open space) where waste is piled up and an industrial building where the segregating process takes place (see Figure 2.7 for pictures of a MRF in London). Trucks and lorries are constantly coming in and out bringing the waste to be segregated and taking out the waste to be recycled.

The overall process may change depending on the MRF, as some facilities have more or less space or technological means and they might send the segregated waste to different recycling facilities which required different standards. Figure 2.6 shows the general process for segregating waste at a MRF, which is described next.

![Figure 2.6: General process of waste segregation at a MRF.](image)

1. Waste arrives (either collected by MRF’s staff or third parties). The ingoing trucks or lorries stand on an industrial scale (weighbridge) where waste is measured as it goes in. Later, each unloaded truck is measured before going out. The mass difference between the loaded and the unloaded truck will be the mass of the ingoing waste.

2. Larger items such as construction beams get removed with a grab. Then the waste goes to the ‘pickers’ station and it is put on a conveyor band where staff are hand-picking recyclable items and throwing them into the respective skip. Recyclable items comprise metal, wood, bricks, and co-mingled waste (plastic, paper and cardboard).
3) The remaining waste is sent to a trommel screen, a giant perforated rotating cylinder. Here waste gets rotated and fine materials fall through the trommel gaps. In this way, fines (small particles of waste material) get separated from the rest of the waste.

4) The rest of the waste may undergo further segregation or grading such as infrared separation. Lastly, whatever is remaining is commonly baled and sent out as Refuse-Derived Fuel to be incinerated for energy recovery. This process is generally considered as recycling and is often takes place abroad (e.g. Netherlands) pursuing the most competitive price. The price per tonne of RDF in the UK fluctuated between £83 and £98 in 2018 (Eurokey Recycling, 2018).

After the segregation process at the MRF, different waste streams are sent to the corresponding recycling facilities or final destinations. Normally, most waste gets downcycled into products that require inferior material quality, little waste gets closed-loop recycled into the same original product, while the remaining waste is used as fuel for energy and a residual percentage is landfilled. Subsection 2.5.4 provides a description of the treatment for common fit-out waste streams.

Figure 2.7 shows photographs taken in one major MRF in the London area. Picture a shows the picking station where the ‘pickers’ are hand-separating visually recyclable items. This segregating stage generally relies on humans, so it creates employment but the accuracy and efficiency of the process is subjective. Picture b shows a pile of segregated metals before being sent abroad for recycling. Picture c displays the mixed waste before the segregation process and picture d shows the segregated fines (after trommel) and the segregated gypsum and plasterboard.

Figure 2.7: MRF in London showing: (a) picking station, (b) segregated metals to be sent abroad, (c) mixed waste before segregation, and (d) segregated fines and gypsum.
2.5 Fit-out waste management

2.5.1 Introduction to fit-out and waste

There is no convention or agreement on the best key performance indicator (KPI) for waste generation during fit-out projects. Common KPIs include tonnes of waste per 100 m$^2$ of gross internal floor area (GFA), tonnes of waste per £100k of project value, m$^3$ of waste per 100 m$^2$ of GFA, and m$^3$ of waste per £100k of project value (CRW, 2009). For this work the KPI of tonnes [t] of waste per 100 m$^2$ of GFA is used. The Construction Resources and Waste Platform (2009) carried out a study based on fit-out waste data contained in the SMARTWaste tool (BRE, 2017) (presented below). Based on four UK office fit-out projects, the reported average rate of waste generation (RWG) for office fit-outs is 6.4 t/100 m$^2$ of GFA, and the average RWG for education buildings, based on two UK fit-out projects, is reported to be 33.7 t/100 m$^2$ of GFA, which is significantly higher than the rate for office buildings.

The Better Building Partnership et al. (2015) in Australia report that standard practice in a fit-out can often lead to up to 80% of material going to landfill, and only 3% being reused. During a case study fit-out, the types and amounts of waste were recorded (as shown in Figure 2.8). It was found that waste summed up to 891 tonnes of material (closer to 10 t/100 m$^2$, rather than the expected average RWG in Australia of 6.3 t/100 m$^2$). Out of this, 536 t of material was recycled, obtaining a landfill diversion rate of 60%. The main waste streams included plasterboard (gypsum board), glass, hardcore (such as concrete, bricks and stone/ceramic), metals, furniture and insulation.

For this Australian case study, timber products and furniture accounted for most of the non-recyclable material. The percentage of non-recycled material (39%), which was considered as mixed waste, was comprised of: composite and laminated timber products (16.8% of total waste); loose furniture not able to be reused through charity (16.8%); carpet tiles (2.5%); ceiling tiles (2.2%); and other construction waste (0.5%).

![Figure 2.8: Percentage (by mass) of each material stream relative to the total waste generation, for a case study office fit-out (BBP et al., 2015).](image)
Hardie et al. (2011) interviewed twenty-three experts in commercial refurbishments in Sydney to find out the average rate of reuse and recycling. They report that building materials and components such as aluminium, structural steel, steel reinforcing bars, bricks, and concrete, are subject to a high level of recycling. However, little recovery is made from the removal of most internal fittings and finishes during the fit-out process as these tend to be designed as short life consumables and are typically installed and demolished according to the rotating needs of tenants (Forsythe, 2010). Moreover, the installation of materials and components on site during the re-fit process involves cutting and fitting, thus yielding a significant amount of waste offcuts.

Another project in Australia (ISF, 2014) performed a series of interviews to identify the main waste contributors during fit-outs. The same few materials were consistently nominated: plasterboard, ceiling tiles, carpet, packaging, furniture (particularly workstations) and the resultant medium-density fibreboard (MDF) and particleboard. It is stated that although some issues can be solved systematically, each material stream needs to be tackled specifically.

There are several studies that focus on management and recyclability of waste arising from the C&D stages of the buildings’ life-cycle (Zhaoa et al., 2009; Huang et al., 2013; Li et al., 2013; Dahlbo et al., 2015; Bovea and Powell, 2016), but there is a need for more research and case studies focusing on waste arising from the occupancy stage of buildings, including the fit-out processes, as these require a different approach of logistics and waste management. For instance, a fit-out project entails that the building may need to remain fully or partially operational, so dismantling measures and space restrictions are important factors.

Li and Yang (2014) identify some of the critical factors that negatively affect waste management in office building retrofit projects in Australia. Based on interviews, they rank twenty of these factors according to their perceived relevance. Lack of motivation to minimise waste was ranked at the top, followed by lack of knowledge and training. Other top-ranked factors include design changes, lack of as-built drawings, not enough collaboration between general contractors and subcontractors, or constrained time schedule.

Other studies related to waste management that may be applicable to fit-out projects include a building information modelling (BIM) system to visualise and improve resource material flows of construction processes and the corresponding waste management activities (Shen et al., 2004; Lu et al., 2006; Sacks et al., 2010). BIM is “a digital technology for describing and displaying information required in the planning, design, construction and operation of constructed facilities” (ISO, 2016), and it usually involves the use of software and/or digital files which can be exchanged or networked to support decision-making within the supply chain.

SMARTwaste is an online waste-management tool designed by the British Research Establishment (BRE, 2017) to fulfil the requirements of the Site Waste Management Plan (SWMP) regulations for new-built construction, refurbishment and demolition projects (CRW, 2010). However, SMARTWaste was developed mainly with new-built construction projects in mind and it collects data more closely aligned with these type of projects (CRW, 2009). A shortcoming of this tool is the fact that it lacks an option to record material that gets reused instead of being sent to a waste-management company.
As mentioned in subsection 2.4.3, waste management is concerned mainly with mitigation of impacts on human health and the environment, rather than resource conservation (Pongrác and Pohjola, 2004). In the building sector, there is a growing need for waste management to shift into “component management” with the aim of increasing the rate of reuse of building components, rather than only setting targets for recycling (Rose and Stegemann, 2018a).

A pre-refurbishment audit (PRA) is a useful waste-management (or component-management) tool in any type of refurbishment project. A PRA identifies, measures and records the types and amounts of material or items to be removed as a result of a refurbishment activity (CRW, 2009). This information may be used to assist in identifying options for reuse, recovery or recycling of those materials or items. A method for conducting PRAs is developed in the present work and used in two of the fit-out case studies.

Buildings as material banks (BAMB) is an approach in which building components in existing constructions are considered as stocks to be used in new buildings or in refurbishment projects (BAMB, 2018; Rose and Stegemann, 2018b). Building components installed in existing buildings can be recorded and tracked using digital identifiers, such as “material passports” (BAMB, 2018) (as later explained in subsection 2.3.5), without the need of a PRA. An effective BAMB information system would function as an interface between supply and demand of salvaged building products; however, as-built records for existing buildings currently tend to be unavailable or unreliable (Rose and Stegemann, 2018b).

2.5.2 Embodied carbon in fit-out

Embodied carbon (EC), is the sum of greenhouse gases (GHGs) released during the production, transport, use and disposal of a product. EC can be measured based on different system boundary conditions as follows: a) cradle to (factory) gate, b) cradle to site (of use) and c) cradle to grave (Circular Ecology, 2020).

In this work, EC of building products is measured from cradle to (factory) gate, which includes emissions from raw material extraction and processing, transport to manufacturer and manufacturing. This allows to identify the EC specifically associated with the production phase of products, regardless of how and where products are used and discarded. EC is normally measured in kgCO$_2$eq, which includes different GHGs in a common unit.

Current standards for embodied carbon assessment of buildings and buildings products include EN 15978, sustainability assessment of construction works, and EN 15804, EPDs. The latter is a product-level standard that feeds into the former building level standard (AIA California, 2020).

As mentioned in subsection 2.3.3, EPDs specify the environmental performance of products from a life-cycle perspective. The relevant standard for EPDs is ISO 14025, where they are labelled as "type III environmental declarations" (Environdec, 2020). EPDs consider different impact categories such as global warming potential, ozone depletion potential, acidification potential, and eutrophication potential, among other. In this this work, EC of products is obtained from the corresponding global warming potential values in EPDs.
Based on an office fit-out in the UK, Abtahi (2006) estimated waste arisings and the associated EC for aggregated elements, such as office furniture or wall covering (as shown in Figure 2.9). As can be appreciated, EC is relative to waste generation for this fit-out case study, so waste is a key factor of a fit-out environmental impact and is one of the focal points of this thesis.

![Figure 2.9: Share of waste arisings and EC in a UK office fit-out (adapted from Abtahi, 2006).](image)

### 2.5.3 Waste Contractors in fit-out

Fit-out projects in non-domestic buildings are normally more “industrialised” than domestic building refurbishments and thus generate high volumes of waste and demand a relatively complex supply chain to collect, transport, and process this waste. At least one Waste Contractor is usually employed to handle all the waste generated during the fit-out project. The Waste Contractor normally provides bins or skips (depending on the project size) for the General Contractor to gather the waste throughout the project. It is normally the Waste Contractor’s responsibility to come to the fit-out site and collect the waste on a regular basis and/or anytime that is required. Waste is then taken to the Waste Contractor’s facilities, where it may be segregated before each different waste stream is sent to the corresponding MRF. At the MRF, waste is normally segregated, cleaned and graded to be sent to the respective final destination, which may include recycling, composting, incineration for energy recovery or landfilling.

The General Contractor (and the upstream stakeholders) tend to sub-contract a Waste Contractor that can ensure a high rate of landfill diversion. This in turn is generally driven by the gradual increase of Landfill Tax, since handing the waste to a Waste Contractor is normally cheaper than direct landfilling. The landfill fee is roughly around £120 per tonne (including Landfill Tax) for non-inert waste, but it may vary according to the landfill site (MRF’s Strategic Sustainability Manager, personal interview, 28 June 2016). The ‘gate fee’ refers to the price that the Waste Contractor charges per tonne of each waste stream collected or received. The gate fee for mixed waste is generally the highest, so it is advisable for the General Contractor to segregate waste on site. In fact, some segregated waste streams are collected free of charge or even paid for (negative gate fee), as is the case for segregated metals, plastics, and paper & cardboard.
Table 2.3 presents approximate gate fees for common fit-out waste streams according to a Waste Contractor’s Environmental and Sustainability Manager (personal interview, 21 October 2016). These costs vary depending on the market and supplier. The corresponding gate fees are divided into two possibilities: waste collected by the waste contractor itself and waste delivered by another company. Metals, paper & cardboard and plastics do not appear in the second possibility (waste delivered) as these waste streams are generally sold elsewhere.

Table 2.3: Gate fees for common fit-out waste streams (Waste Contractor’s Environmental and Sustainability Manager, personal interview, 21 October 2016).

<table>
<thead>
<tr>
<th>Waste stream</th>
<th>Gate fee (£/t)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>If collected by the Waste Contractor itself</strong></td>
<td></td>
</tr>
<tr>
<td>Mixed waste</td>
<td>100</td>
</tr>
<tr>
<td>Plasterboard</td>
<td>60</td>
</tr>
<tr>
<td>Wood</td>
<td>50</td>
</tr>
<tr>
<td>Hardcore</td>
<td>0 to -5*</td>
</tr>
<tr>
<td>Metals, Paper &amp; Cardboard, Plastics</td>
<td>0 to -100*</td>
</tr>
<tr>
<td><strong>If delivered by another company</strong></td>
<td></td>
</tr>
<tr>
<td>Mixed waste</td>
<td>100</td>
</tr>
<tr>
<td>Plasterboard</td>
<td>80</td>
</tr>
<tr>
<td>Wood</td>
<td>60</td>
</tr>
</tbody>
</table>

*Minus sign means waste streams are paid for.

2.5.4 Fit-out waste treatment

2.5.4.1 Introduction to fit-out waste treatment

This section presents the common waste streams found during fit-out projects and their respective treatment, including the separation process at the MRF and the subsequent recycling process at the respective recycling facilities. The following waste streams are divided into materials and components, where materials refer to material streams such as plastics or metals which are generally associated with an EWC code, while components comprise building products that can be broken down into different sub-components, such as a light fitting which can be further separated into plastics and metals. Most building components found in fit-outs are not associated with an EWC code.

2.5.4.2 Materials

Asbestos

The EWC code for waste asbestos is 17 06 05. Asbestos can be found in building applications such as cladding or thermal and acoustic insulation, and it is classified as a stable, non-reactive hazardous waste (SNRHWH) (EA, 2010). This type of material was widely used in the 19th century because of its high tensile strength, sound absorption and fire resistance. However, prolonged inhalation of asbestos fibres can cause adverse health effects to occupants, such as lung cancer or asbestosis. For this reason, asbestos for building applications were banned in many countries through the 1980s and 1990s (1999 in the case of the UK). Disposal of asbestos must be done through an Asbestos Removal Contractor, which usually buries this type material in a procedure known as deep landfill burial.
Ceramics

The EWC code for waste ceramics is 17 01 03. Ceramics are found in building components such as floor/wall tiles, sinks, and toilets. This type of material is generally treated as hardcore (as detailed below) and follows the same recycling process. It is feasible to reuse ceramic components due to their long lifespan and their relative standardisation.

Glass

The EWC code for waste glass is 17 02 02. Commonly found in window panes, partitions and office furniture, glass is usually recycled due to its mass and the ease of recycling. However, it is hardly ever recycled into its original use because of the risk of contamination to the production line. The lack of standardisation in glazed assemblies makes it difficult to reuse them (ISF, 2014).

Glass is separated from other recyclables and sorted using mechanical and manual techniques. It is then crushed, screened and washed to produce fine glass particles (<4mm) which are sold as aggregate material. The remaining material (>4mm) is further processed; where optical sorting equipment detects and ejects non-glass particles, to be then sent to glass manufacturers, where glass is re-melted into new glass products.

The aggregate can be used for construction (such as building blocks) and civil engineering applications. The re-melted glass can be turned into bottles, jars or glass wool (loft insulation).

Gypsum (including plasterboard)

The EWC code for waste gypsum-based material is 17 08 02. This material generally accounts for a high share of the waste generated during fit-outs (ISF, 2014). Gypsum is commonly used for wall and ceiling plastering (adding a gypsum layer) and plasterboarding or drylining. In the latter, pressed gypsum covered in two paper layers is used for wall and ceiling covering and for partition walls.

Plasterboard is separated using mechanical and manual techniques into its constituent material streams which are re-processed separately: paper (backing), metals (studwork, nails/screws), and gypsum core (around 90% of the content).

Gypsum is crushed into fine powder and can be used as feedstock for new plasterboard manufacture (as is the case for British Gypsum or Knauf plasterboard), moisture absorbents, interior wall blocks, constituent in concrete manufacture, or as compost for agricultural purposes. In the case of landfilling, gypsum is classified as a SNRHW (EA, 2010), and it must be disposed in special landfills as it off-gasses hydrogen sulphide (UK Government, 2010).

Plasterboard is normally cut during installation and is often broken during strip-out, so the design of size-standardised and modular plasterboard would potentially increase its reuse rate.

Hardcore

The EWC code for waste hardcore is 17 01 07. Hardcore comprises a mixture of solid materials, including concrete, brick, gravel, ceramic, marble, and screed, and thus the management options for this material stream are complex.
Broadly, after mechanical pre-segregation jaw crushers crush the hardcore while metals contaminants are removed magnetically. Then the material is washed, screened and graded by size, producing aggregate products ranging from sharp sand to 75mm gravel. Some of this aggregate may be suitable for purposes such as ground floor slab or highway paving.

**Hazardous waste**

There is no EWC code for general hazardous waste. Hazardous waste in fit-outs include paints and adhesives, mercury-containing items such as fluorescent lamps (see below) and batteries, as well as compressed units such as fire extinguishers or freezers. Hazardous waste is sent to its respective ATF.

**Insulation**

The EWC code for waste insulation is 17 06 04. Insulation materials are common waste streams found during fit-outs. Insulation materials can be broken down into organic (carbon-containing) and inorganic (Cuce et al., 2014). Organic insulation includes natural materials such as cork, sheep wool, cotton wool or cellulose as well as chemically synthesised materials such as polystyrene or polyurethane. Inorganic insulation materials include glass wool, rock wool and mineral wool.

Although insulation materials are commonly found during fit-outs, these materials present lower mass relative to other materials due to their low density. This fact makes them less desirable for recycling compared to other materials such as metals. Insulation materials can be recycled into downgraded products which require poorer thermal properties such as protective packaging or outdoor furniture.

Barriers to the reuse of insulation include safety issues and the fact that material is generally cut to fit purpose. Size standardisation and modular assembly would facilitate the reuse of insulation.

**Metals**

The EWC codes for waste metals are 17 04 01 (copper, bronze, brass), 17 04 02 (aluminium), 17 04 03 (lead), 17 04 04 (zinc), 17 04 05 (iron and steel) and 17 04 06 (tin). This type of material constitutes a high proportion of the total waste mass in fit-outs due to its relatively high density. Metals are sought-after for recycling due to their market price, their density and their facility for recycling (ISF, 2014). Metals can be broadly broken down into ferrous metals (iron-containing and thus magnetic) and non-ferrous metals. Metals are used in several building components such as wall stud framing, RAF, ductwork, office furniture, and WEEE.

Ferrous and non-ferrous are separated through magnetic induction before being further segregated by different processes into specific metal types. Generally, all metals are cleaned, shredded, melted down and re-cast into a variety of end uses. Metals are also often sent abroad (e.g. Spain, Turkey) as bulk prices offered there can be more competitive.

Ferrous metals are commonly used as feedstock for new steel production. Non-ferrous metals diversify into a variety of end uses. For example, copper can be used for electrical appli-
cations, piping, roofing, insulation and household items; zinc is commonly used as anti-corr-
rosive; lead gets mostly used for batteries; and tin is used to make cans and for various pur-
poses in the automotive industry.

Mixed waste
The EWC code for mixed waste is 17 09 04. Also known as general mixed waste, it accounts
for a significant share of the waste generated in building fit-outs. Normally, Fit-out or Strip-
out Contractors segregate some of the materials and components into different waste
streams, but much or most of the waste is commonly unsegregated and goes out as mixed
waste. Mixed waste may include any waste stream that was not segregated, as well as anything
generated during the process that is not inherently part of the building such as offcuts, boxes,
packaging or spare material.

Mixed waste is segregated into different constituent waste streams at the Waste Dealer’s
MRF and sometimes at the Waste Contractor’s Transfer Site, if the scale of their activity
and/or the size of their premises allows it.

Paper and Cardboard
The EWC code for waste paper and cardboard is 20 01 01. Paper products are found in
building applications such as plasterboard or ceiling tiles (cellulose). Cardboard is often
found in packaging for building components.

Paper and Cardboard are mechanically and manually segregated. Once segregated different
types of material are bulked and baled into mill-sized bales for bulk transportation for recy-
ing. In the recycling process, this waste stream is commonly mixed with water and chemi-
cals to create a mixture called slurry or pulp, to then be dried, rolled and cut. Paper and
cardboard are often sent abroad (e.g. China) where the recycling process may be ambiguous.

Recycled paper and cardboard can be used for the manufacture of products such as newsprint,
cardboard, packaging, or tissue.

Plastics
The EWC code for waste plastics is 17 02 03. There are many different types of plastics or
polymers found in several building components, however, there are two main kinds of plas-
tics: thermoplastics and thermosetting polymers (thermosets). All plastics fall under only one
EWC code, although this classification should differentiate between the two main kinds of
plastics, which would likely lead to better end-of-life treatment. Thermoplastics are mould-
able above a specific temperature and solidify upon cooling, and as these present no chemical
change during this process, they can be re-moulded repeatedly up to a certain limit. Con-
versely, thermosets undergo a chemical reaction when they are melted so they can normally
melt and take shape only once. Thermosets normally cannot be recycled into the same prod-
uct, so they are commonly used as filler material to lower the consumption of more expensive
binder materials. However, emerging techniques are enabling higher rates of thermoset re-
cycling.

Plastics are separated, sorted and baled for bulk transport to recycling facilities where mate-
rial is ground and passed through a series of cyclones and water baths to be further segregated
into different plastic types. Then the product is either melted down directly and moulded
into new shapes or shredded into flakes before being melted down and processed into granules. Plastics are often sent abroad (e.g. China) where the recycling process may be ambiguous.

Poly-Vinyl Chloride (PVC) can be closed-loop recycled into new PVC products (such as window frames) up to a limited number of cycles. Although good for recycling, there are plenty of studies showing adverse health effects of PVC (Nelson, 2002). Other reclaimed plastics are used for low-quality manufacturing applications such as damp-proof membranes, drainage pipes, ducting, flooring, hoardings, or scaffolding boards.

**Textiles**
The EWC code for waste textiles is 20 01 11. Different kinds of textiles are found in curtains, office chairs, wall coverings, and some carpets, among other applications. Textiles do not generally represent a major share of fit-out waste and very often go out as mixed waste (see above).

If segregated, then textiles can generally be shredded and processed back into fibres to create a new yarn or to be used directly for making new products such as building insulation or carpet padding. Conversely, polyester-based textiles can be shredded and processed into polyster chips which are then melted and used for creating new fibres.

**Wood**
The EWC code for waste wood is 17 02 01. Wood (also known as timber) includes any products that are mostly made up of wood. This waste stream also includes fibreboards (such as MDF) and particleboards which go as ‘dirty wood’ as they contain a binder substance (usually urea formaldehyde). Wood-containing building components include floorboards, furniture, joinery, doors and window frames.

Undamaged timber items can be segregated for potential reuse. Good quality timber is removed from lower quality wood waste to be sent to a processing facility as it has sufficient value to do so. Other wood waste is cleaned and any contaminants such as plastic and metals are removed manually before being processed through shredders with overbound magnets to extract smaller ferrous metal items.

Reclaimed wood: can be reused during the building phases of construction projects as structural beams, non-structural cladding, fireplace lintels, or garden furniture. Reclaimed floorboards can be used for ceilings, interior cupboards, shelves, radiator covers, benches, or industrial shelving. Good quality timber is reconstituted as wood-chip for the building trade (e.g. particleboard), while low-quality grades are used as mulch or bedding for agricultural or horticultural purposes. Contaminated timber products (e.g. painted) are generally incinerated for energy recovery.

**2.5.4.3 Components**
In general, there are EWC codes for building components but just for their constituent materials. Some of these constituent materials can be of a significant value but come in very small quantities. For example, gold in circuit boards, phosphorous in fluorescent lights and
Literature review

rare earth materials in WEEE. These trace elements are so dispersed that is often not financially viable to recover them and so they end up in landfill, are incinerated or dispersed into the environment.

**Carpet and carpet tiles**
Carpet and carpet tiles are some of the most common types of floorings in office buildings in the UK. Carpet is usually made up of a polymer backing and a synthetic fibre on top, such as polypropylene, nylon or polyester, so it normally goes out as mixed waste (see above).

Carpet can be separated into its constituent materials for recycling into different products. However, companies such as Desso, Forbo or Interface have implemented innovative takeback schemes in which they can take back their end-of-life products as feedstock into their manufacturing process.

Negligible onsite reuse takes place as carpet usually gets damaged or stained over time and aesthetics is the main driver for changing the flooring (ISF, 2014). However, carpet is often sent to charity to be reused abroad. Carpet is usually cut to fit space and glued to the floor, which complicates non-destructive removal and reuse. Carpet tiles are easier to remove than carpet and innovative pattern designs make it feasible to replace just one tile without compromising aesthetics.

**Ductwork**
Ductwork is part of the HVAC system and is sometimes stripped out during building fit-outs. Ductwork is most commonly made of metal (usually galvanised steel) but can also be made of PVC or fibreglass. Ductwork can be adapted and reused for subsequent fit-out projects but is normally recycled as its metal composition makes it more attractive for recycling rather than reuse. Modular assembly and installation would increase the circularity potential of ductwork, by facilitating non-destructive removal and reuse.

**Door**
Doors are building components almost always present in building fit-outs, and they can be made of glass, metal, plastic, timber or a combination of these. When doors are made up of one single material type, they are incorporated into the corresponding waste stream, otherwise, the different materials can be separated and then incorporated into the respective material stream.

It is feasible to retain doors *in situ* during fit-out projects, due to its relatively long lifespan and the possibility of restoring them when they are visually deteriorated. If doors are stripped out, it is rather difficult to reuse them in other fit-out projects due to a lack of size standardisation.

**Electrical socket**
An electrical socket is one of the most common building components stripped out during fit-outs. These components typically contain plastic and metal. These can be tightly integrated and can be very difficult to separate into the different materials. To be recycled, electrical sockets will need to be ground and then separated into their constituent materials and each material then incorporated into their respective waste stream.
These components can easily present lifespans longer than fit-out cycles, so it is feasible to reuse these components for subsequent fit-out projects. However, electrical sockets stripped out during fit-outs are typically treated as waste and the constituent materials get recycled; sockets are hardly reused across fit-out projects. This is partly due because inspecting and re-certifying before re-installing represents more time and effort, and new sockets are relatively cheap. A market of scale for re-certified sockets would likely increase the reuse rate of these components.

Fluorescent light
The EWC code for waste fluorescent lights and mercury containing waste is 20 01 21. Fluorescent lights such as light tubes have until very recently been the most common type of lights used in non-domestic building fit-outs. Although LED lights are gradually becoming more common, no LED lights were found during this study (and during the fit-out case studies). Fluorescent lights are composed of a phosphor-coated glass bulb, an infill of pressurised mercury and a noble gas (usually argon) and a base pin made of aluminium and ceramic (DOE, 2014). Fluorescent lights are commonly treated as hazardous waste due to their pressurised content.

They need to be processed in a special facility, where during the recycling process, the tubes are fed into a specialised machine that contains a built-in particle filter and carbon absorption system to minimise exposure to mercury vapour and phosphor dust. The materials are then separated to be recycled. After separation, each material type is treated differently. Aluminium is incorporated into the aluminium stock, glass cullet can be used for new fluorescent tube manufacture, and mercury contaminated phosphor powder is distilled to produce pure mercury. The residual phosphor powder can be used in the manufacture of new fluorescent tubes.

Hardly any fluorescent lights get reused due to their fragility. Removal and transportation of these components may damage them or cause malfunctioning. Accordingly, fluorescent tubes would need to be tested before re-installing which would require more time and money. While the recycle rate for these tubes is increasing, their current recycling rate in the UK is below 50% (MRW, 2018).

Light fitting
A light fitting is the unit holding the light-emitting bulb or tube in place and is one of the most common building components stripped out during fit-outs. These components are typically made up of plastic, metal, or a combination of these, they may contain sockets (made of a phenolic resin or ceramic) and a ballast with a metal casing and circuit board inside. The different materials in light fittings can be separated and incorporated into their respective waste streams.

Although light fittings can be easily reused due to their relative long lifespan, they are normally treated as waste and are recycled or end up as mixed waste. Barriers to the reuse of these components include lack of size standardisation, safety issues or need of testing and potential damage during transportation. Light fittings have been changing rapidly in recent years due to energy efficiency improvements making it financially viable to replace the entire
fitting. In most cases this has taken no account of the resource consumption and is entirely a financial decision on expected energy savings.

**Office furniture**
Office furniture usually comprises workstations, desks, chairs, lockers, drawers and shelves. These items can be composed of different materials such as metal, glass, wood or MDF, so they are normally treated as mixed waste and their recycling process can be complicated when their constituting materials are difficult to separate.

The reuse of office furniture is getting more common nowadays as it is possible to easily reuse these items for subsequent fit-out projects or distribute them through charitable organisations. Office furniture is currently a significant share of the products found in reuse platforms such as Globechain (2019) or Warpit (2019). On the other hand, Rype Office (2019) is serving as a reuse third party by selling remanufactured office furniture at half price of new. Besides the lower price, reused office furniture might also have the advantage of off-gassing less volatile organic compound (VOC) pollutants than brand new furniture.

**Resilient flooring**
Resilient flooring includes linoleum, rubber, cork and vinyl products. These items normally go out as mixed waste and get later segregated into the respective waste stream.

Negligible reuse of resilient flooring takes place due to usual deterioration and because this type of flooring gets easily damaged when removed. Old resilient flooring and flooring off-cuts can be recycled into different products such as traffic cones. Companies like Forbo and Tarkett can use their end-of-life products into their manufacturing process. Linoleum and cork can also be incinerated or used as compost. Circular design issues are similar to those of carpet in that resilient flooring materials suffer visual deterioration and are often glued down which makes it difficult to remove without damage.

**Raised access floor**
Raised access floor (RAF) is commonly used in non-domestic building fit-outs as it provides space for M&E services to be concealed and protected. RAF is often composed of a core (generally particleboard or cementitious material) covered by steel cladding and adjustable height supports called pedestals. When recycled, RAF is segregated into its constituent materials (e.g. wood and metals).

Due to its long lifespan, RAF is often reused on site where only the floor covering (carpet or resilient flooring) gets replaced. Although RAF can easily be reused off site due to its relative size standardisation, this rarely takes place since it is logistically difficult to quickly find new users for the items. Another barrier for reuse is that the support pedestals, which might need replacement, must be supplied by the original manufacturer but often get discontinued.

**Suspended ceiling tiles**
Suspended ceiling tiles are a common component in non-domestic building fit-outs. These components can be made up of fibreglass, cellulose, mineral fibre or metal, so they often go out as mixed waste. Suspended ceiling tiles rely on a suspension system (i.e. ceiling tile rails) generally made of metal.
When recycled, ceiling tiles are incorporated into waste streams according to their material composition. As in the case of carpet tiles, there are innovative take-back schemes (e.g. Armstrong (2019)) in which end-of-life ceiling tiles can be collected by the original manufacturer and remanufactured or closed-loop recycled.

However, negligible reuse of ceiling tiles takes place due to visual deterioration, lack of size standardisation, and because they can get easily damaged during transportation.

**Waste electrical and electronic equipment**

The EWC code for waste electrical and electronic equipment (WEEE) is 20 01 36. WEEE constitutes practically anything with an electricity plug or a battery. Within building fit-outs, common EEE constitute kitchen appliances and IT equipment. Although fluorescent lamps and light fittings are technically WEEE, these are generally not categorised within this waste stream in the fit-out industry.

WEEE is transported to an ATF where reuse or recycling takes place. Typically, this involves techniques from depollution to disassembly, shredding, recovery or preparation for disposal. The UK recycling rate for WEEE is 50% (Eurostat, 2016).

### 2.6 Environmental assessment of fit-out

#### 2.6.1 Industrial ecology

The interaction between socio-economic and environmental systems can be studied through the science of “industrial ecology” (Udo de Haes, 2002). Industrial ecology is “the study of the flows of materials and energy in industrial and consumer activities, of the effects of these flows on the environment, and of the influences of economic, political, regulatory, and social factors on the flow, use, and transformation of resources” (White, 1994, as cited in Ayres and Ayres, 2002).

Industrial ecology relies on the concept of “environmental accounting” (Ayres and Ayres, 2002), which is “the identification, allocation and analysis of material streams and their related money flows” in a system to provide insight on environmental impacts and financial effects (Steele and Powell, 2002, as cited in De Beer and Friend, 2006). This entails the foundation of sustainability assessment techniques in economic activities.

A distinction can be made between sustainability assessment methods which are performed in physical terms and studies based on monetary terms (Udo de Haes, 2002). Studies performed in physical terms have their historical roots in the 19th century and go back to Marx and Engels, who used the term “metabolism” (Stoffwechsel) to imply a material relation between man and nature (Udo de Haes, 2002). Studies in physical terms include material flow analysis (MFA) and life-cycle assessment (LCA), which are both later described in subsection 2.6.2.

On the other hand, studies in monetary terms may take the environment into account as physical extensions of monetary models, like the input-output analysis (IOA) developed in the 1980s (Leontief 1986), or they may address the environmental consequences of economic activities in monetary terms, as in the cost-benefit analysis (CBA).
Industrial ecology depends more on physical than on monetary environmental accounting (Ayres and Ayres, 2002), and therefore MFA and LCA are the two primary tools in industrial ecology (Kaufman, 2012). Although sustainability assessment methods can assess the environmental impact of economic activities and provide useful insight for decision- and policy-making, these methods do not adequately address the creation and dissipation of multidimensional value that spans the social, environmental, economic and technical domains (Iacovidou et al., 2017).

2.6.2 Material flow analysis and life-cycle assessment

This work uses material flow analysis (MFA) as a research tool to analyse physical flows in building fit-out processes. An MFA, also referred to as material flow accounting, is a systematic overview of material flows and stocks, over both time and space, within a defined system (Brunner and Rechberger, 2004). It analyses the throughput of process chains comprising extraction or harvest, chemical transformation, manufacturing, consumption, recycling and disposal of materials, and it is based on physical units (usually mass) to quantify the inputs and outputs of those processes (Bringezu and Moriguchi, 2002). MFA is based on the mass balance principle, derived from Lavoisier’s law of mass conservation (Lavoisier, 1789; as cited in Van der Voet, 2002).

In general terms, material flow studies comprise the following three-step procedure (Van der Voet, 2002): (a) definition of the system, (b) quantification of the stocks and flows, and (c) interpretation of the results. MFA has been used in a number of studies to present an overview of material flows in different economic systems to support the identification and development of policies for resource conservation (Geyer et al., 2017; Aryapratama et al., 2019; Brouwer et al., 2019; Noll et al., 2019; Shanks et al., 2019).

MFA can support life-cycle assessment (LCA) to define the boundary of the system under analysis, as well as supporting the life-cycle inventory (LCI) and providing information on product’s end-of-life destinations.

LCA is a methodology used to analyse complex processes dealing with the input and output flows of materials, energy, and pollutants to and from the environment from a life-cycle perspective (Perez-Garcia et al., 2005; Ding, 2014). The idea for LCA was conceived in the late 1960s with energy consumption being the focal issue and since the early 1970s, wastes and emissions generated by the production processes have also been taken into account (Azapagic, 1999). The LCA methodology was officially developed in 1993 by the Society of Environmental Toxicology and Chemistry (Consoli, 1993), and in 1997 the International Organization for Standardization (ISO) published the first ISO 14040 series to standardise the guidelines of the LCA methodology (Perez-Garcia et al., 2005).

In the building sector, LCA has been used since 1990 (Ortiz, 2009) and it is increasingly gaining attention and acceptance. Although building LCA case studies are difficult to compare (Buyle et al., 2013; Cabeza et al., 2014), there is a consensus that the occupancy stage of buildings always has the highest percentage (up to 90%) of environmental impact in the life-cycle of a building (Adalberth, 2001; Kofoworola and Gheewala, 2008; Sharma et al., 2011).

Ortiz et al. (2009) and Bayer et al. (2010) define building LCA tools into three levels:
1. environmental performance at material level (helpful to guide in the material and product selection process);
2. whole building decision-making;
3. environmental building assessment framework, such as BREEAM (2016) in the UK, or the internationally developed Living Building Challenge (ILFI, 2019). Figure 2.10 shows the basic and general framework for level 3 LCA tools.

Even though LCA has a great potential to make processes more efficient and reduce their environmental impacts, these tools present some limitations (Ding, 2014):

- the method relies on the availability and completeness of the material flow data;
- it is difficult to determine the lifespan of building products since it is affected by variables such as user patterns, maintenance, and climatic conditions;
- results are not fully comparable since LCA tools, boundaries and functional units are different;
- it is difficult to know whether a product or material will be disassembled and reused or recycled (because this only takes place in the future).

![Figure 2.10: Framework for level 3 LCA tools: environmental building assessments (Ding, 2014).](image)

### 2.6.3 Fit-out certification methods

#### 2.6.3.1 Introduction to fit-out certification methods

Assessment and certification methods for construction and refurbishment projects are loosely based on an LCA model (as can be appreciated from Figure 2.10), and they can support the sustainability of building projects. However, the uptake of building assessment or certification methods is hampered by presumed high certification costs. The current share of certified commercial buildings is as low as 0.04% (and 0.32% for residential buildings). It is estimated that this share will grow to 0.27% in 2020 and 0.98% in 2030 (ECORYS, 2014), so the use of building assessment methods is increasing at a relatively high rate.

Common commercial assessment methods that are applicable to building fit-outs include SKA Rating, BREEAM, LEED, and Green Star. These certifications schemes aim to reduce the environmental pressures of building projects while increasing occupants’ comfort and well-being. Table 2.4 provides a summary of these methods, with relevant references, which are explained with more detail next.
<table>
<thead>
<tr>
<th>Assessment method</th>
<th>Owned by</th>
<th>Schemes offered</th>
<th>Credit categories</th>
<th>Rating scale</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>SKA Rating (RICS, 2016)</td>
<td>Royal Institution of Chartered Surveyors (RICS)</td>
<td>Offices, Retail, and HEI</td>
<td>Energy &amp; CO₂ emissions, Pollution, Wellbeing, Materials, Waste, Water, Transport, and Project Delivery</td>
<td>Gold, Silver and Bronze</td>
<td>The cost for a formal certification is £355</td>
</tr>
<tr>
<td>Green Star (GBCA, 2016)</td>
<td>Green Building Council of Australia (GBCA)</td>
<td>Design &amp; As Built, Interiors, Performance, and Communities</td>
<td>Environment, Liveability, Innovation, Governance, and Economic Prosperity</td>
<td>Certified or not-certified</td>
<td>The “Interiors” scheme is applicable to building fit-outs and costs between £8,500 to £19,500</td>
</tr>
</tbody>
</table>
2.6.3.2 SKA Rating

SKA Rating is an environmental assessment method designed exclusively for non-domestic fit-outs, and it is led and owned by the Royal Institution of Chartered Surveyors (RICS). SKA Rating was founded by Skansen, an interior construction company, which in 2005 initiated a research project with RICS and AECOM to establish whether it was possible to measure the environmental impact of fit-outs to remove the ambiguity prevalent in the refurbishment industry (RICS, 2016).

This assessment method comprises three schemes for different building types: Offices, Retail, and HEI. There is an online assessment tool (RICS, 2017), which can be used (for free) informally, or for formal certification using an accredited assessor and can be certified on a scale of Gold, Silver and Bronze. SKA Rating is carried out against a set of sustainability good practice measures (GPMs) covering different credit categories as shown in Table 2.5.

<table>
<thead>
<tr>
<th>Credit category in SKA Rating</th>
<th>Examples of GPMs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy &amp; CO₂ emissions</td>
<td>Reducing lighting energy use. Using energy-efficient HVAC.</td>
</tr>
<tr>
<td>Materials</td>
<td>Assessing material sustainability of elements such as finishes or furniture (e.g. whether they are reused or certified).</td>
</tr>
<tr>
<td>Waste</td>
<td>Reducing waste sent to landfill during the fit-out process (e.g. general C&amp;D waste, furniture, ceilings, doors).</td>
</tr>
<tr>
<td>Water</td>
<td>Reducing water in use. Installing water-efficient taps.</td>
</tr>
<tr>
<td>Transport</td>
<td>Providing cycle parking. Creating a travel plan.</td>
</tr>
<tr>
<td>Project Delivery</td>
<td>Developing a building user guide. Incorporating social-value actions.</td>
</tr>
</tbody>
</table>

The cost for a formal certification is £355 (RICS, 2016). This is the most affordable assessment method out of the ones presented here, and it was used in three of the fit-out case studies analysed in this work (as detailed later in section 4.3).

2.6.3.3 BREEAM

BREEAM (Building Research Establishment Environmental Assessment Method) is the world’s first sustainability assessment method for masterplanning projects, infrastructure and buildings. This assessment method was first launched in 1990 and is owned by BRE Global.
Ltd. BREEAM accounts for most of the sustainable certificates for renovations and new buildings in Europe (BRE, 2016).

BRE’s assessment method independently addresses four stages: Masterplanning, New Construction, In-Use, and Refurbishment & Fit-out. The procurement, design, construction, and operation of a development are evaluated against targets (called credits) that are based on performance benchmarks. Assessments are carried out by independent, licensed assessors, and are certified on a scale of Pass, Good, Very Good, Excellent, and Outstanding (BRE, 2016). The “Refurbishment & Fit-out” scheme is applicable for building fit-outs and costs between £750 to £4,900 (BRE, 2016).

**2.6.3.4 LEED**

LEED (Leadership in Energy and Environmental Design) is a building certification system developed in the US in 1994 by the US Green Building Council (USGBC, 2016), loosely based on BREEAM.

This assessment method includes four different rating systems, depending on the type of project: Building Design and Construction, Interior Design and Construction, Building Operation and Maintenance (O&M), Neighbourhood Development, and Homes. Assessments are carried out by certified assessors against a series of credits and rated on a scale of Certified, Silver, Gold, and Platinum (USGBC, 2016). The “Interior Design and Construction” rating scheme is applicable to building fit-outs, and it costs between £1,900 to £19,300, depending on the project’s GFA, plus a £800 registration fee (USGBC, 2016).

**2.6.3.5 Green Star**

Green Star rating was launched by the Green Building Council of Australia in 2003, and it is the national and voluntary rating system for buildings and communities (GBCA, 2016).

The Australian assessment method is constituted by five different rating tools to address the type of project: Design & As Built, Interiors, Performance, and Communities. It is rated on a twofold scale of certified or not-certified (GBCA, 2016). The “Interiors” scheme is applicable to building fit-outs and costs between £8,500 to £19,500 (GBCA, 2016).

**2.6.3.6 European Commission guidelines**

Concerned with the low uptake of building assessments in Europe, the European Commission developed a common framework of core indicators to assess the environmental performance of buildings throughout their life-cycle (European Commission, 2014a). This framework aims to facilitate the effective transfer of good practices from one country to another and is proposed to be flexible so that it can be integrated in existing and new assessment schemes. The core indicators proposed by the Commission fall within the following areas: total energy consumption, use intensity of buildings, indoor comfort, material use, durability of products, recycled content of materials, recyclability and reusability of materials and products, DfD, management of C&D waste, and water use.

As complementary actions, the Commission will support research and innovation projects in the following aspects regarding circularity within the built environment:

- recyclability audits of buildings designated for demolition or reconstruction;
- development of onsite C&D waste separation techniques and practices;  
- development of technologies for processing C&D waste into high quality recycled materials and incentivising producers of construction products to use recycled material;  
- development of collaborative schemes between demolition and construction product sectors, to share cost and benefits of C&D waste recycling.

2.7 Summary of the literature review

The circular economy model aims to substitute the current linear production and consumption scheme and to decouple environmental pressures from economic growth. In a circular economy there is no such thing as waste, so products are designed to last, to be repaired, remanufactured, reused and closed-loop recycled.

The construction industry in the UK consumes more than 380 million tonnes of resources annually and accounts for 32% of the annual waste generation, where less than 1% of recovered materials are reused, and only 20% are used for producing new building products, while the rest are downcycled.

Fit-outs relate to the most frequently replaced layers in the built environment and therefore account for the most recurrent replacement of building products, which reportedly include plasterboard, ceiling tiles, carpet, and furniture, among other. There is thus a significant scope for higher resource circularity in building fit-outs, and waste management plays a crucial role in this agenda.

The UK Landfill Tax has made alternative waste-management systems more affordable than landfilling; however, this has resulted in an increase of the next cheapest alternatives, such as incineration and export, and policies to re-insert landfill-diverted materials into the economy are now needed.

Industrial ecology accounting methods such as MFA and LCA are useful tools to analyse the environmental impacts of fit-out processes and to support the development of policies for resource conservation. On the other hand, commercial certification schemes for refurbishment projects can support the sustainability of building projects, but they have low uptake and do not fully cover the circular economy concept.

An increasingly complex set of technical, informational and organisational mechanisms can increase the circularity in the built environment, such as building in layers, designing for deconstruction, material passports or CLSCs. All of these elements need to be further studied, developed and effectively combined to achieve higher circularity in building fit-outs.

Although a few studies have addressed the issue of waste generation and management in office fit-outs, there is still a knowledge gap about the pathways and final destinations of fit-out wastes, and the interaction among supply-chain stakeholders has not been sufficiently studied.

In this work, a socio-technical analysis for office and HEI building fit-outs is developed as a base for the identification of potential improvements in the fit-out process and in the design of building components, aiming to make these practices more circular, as detailed in the next chapter.
3 Methodology

3.1 Overview of methodology

This chapter presents the aims of the study along with the corresponding research methods. The overarching research question is concerned with how the process of building fit-outs and the design of building products can become more circular. The main research objective was thus to identify potential improvements in the fit-out process and the design of building products to maintain the value of materials as high, and for as long, as possible. This research problem can be tackled from different angles, as building fit-outs are complex services that include technical, organisational and regulatory dimensions. Therefore, several research sub-questions were proposed, as shown in Table 3.1, aiming to address the different dimensions of the research problem.

A mixed-methods approach was followed to study the research problem from both a technical and a social perspective, so the study’s approach is both quantitative and qualitative. Accordingly, the present work relies on observations and measures carried out during fit-out case studies and it is also underpinned by personal interviews conducted during the case studies and conducted independently with people related to the fit-out industry. In total, five fit-out case studies were analysed (see Table 3.7) and 31 supply-chain actors were contacted (see Table 3.4). All personal and commercial information was anonymised for data protection purposes.

Section 3.2 presents the methodological design, including the research tools used to approach the research tasks and to answer the corresponding research questions. Section 3.3 summarises the overall research outline to offer a clearer perspective of the methodological structure and the research outcome. Section 3.4 discusses and justifies the mixed-methods research approach, and section 3.5 covers the measures taken for data protection and risk assessment.

3.2 Research design

3.2.1 Research questions

The research methods were selected according to the specified research questions. Table 3.1 presents the overarching research question and summarises the research sub-questions (i-vi) along with the corresponding research tasks and research tools. Further explanation of the research tasks and methods used are presented below in subsections 3.2.2 to 3.2.7.
Table 3.1: Research questions and the corresponding research tasks and research tools.

<table>
<thead>
<tr>
<th>No.</th>
<th>Research question</th>
<th>Research task</th>
<th>Research tool</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>How can the process of building fit-outs and the design of building products become more circular?</strong></td>
<td>Identify potential improvements in the fit-out process and the design of building products to maintain the value of materials as high, and for as long, as possible</td>
<td>All the research tools below</td>
</tr>
<tr>
<td>i</td>
<td>Who are the relevant actors involved in the fit-out process?</td>
<td>Map out the stakeholders within the fit-out supply chain</td>
<td>Exploratory interviews with people related to the fit-out industry using chain-referral sampling</td>
</tr>
<tr>
<td>ii</td>
<td>How do the different actors in the supply chain interact throughout the fit-out process?</td>
<td>Define the function of actors/stakeholders across the stages in the fit-out process and define the relations among them. Evaluate their impact on the material flow</td>
<td>a) Qualitative analysis of interviews; b) Observations during fit-out case studies and analysis of observational diary</td>
</tr>
<tr>
<td>iii</td>
<td>Which are the prevailing building materials and components found in fit-outs?</td>
<td>Determine the key materials and components that get installed and removed during the fit-out process and the EE associated with these</td>
<td>a) Questionnaires to Site Managers and Waste Contractors; b) Onsite observations at fit-out case studies and MRFs, and analysis of observational diary; c) PRA</td>
</tr>
<tr>
<td>iv</td>
<td>Which are the main types of wastes generated and how much of these are generated during the fit-out process?</td>
<td>Identify and measure the waste streams generated in the fit-out process</td>
<td>a) Onsite observations during fit-out case studies and analysis of observational diary; b) Cross-examination of Waste Reports</td>
</tr>
<tr>
<td>v</td>
<td>Where do the different waste streams go and what happens with them throughout the supply chain?</td>
<td>Trace paths and final destinations of wastes from fit-out case studies</td>
<td>a) Structured interviews to Waste Contractors, MRFs and waste final destinations; b) MFA</td>
</tr>
<tr>
<td>vi</td>
<td>What are the incentives, mechanisms and barriers for a circular fit-out?</td>
<td>Identify the key incentives that encourage higher rates of (closed-loop) recycling and reuse, the current and potential mechanisms to efficiently carry it out, and the barriers that hinder circularity in the fit-out industry</td>
<td>a) Literature review analysis; b) Qualitative analysis of interviews; c) Observations during fit-out case studies and analysis of observational diary</td>
</tr>
</tbody>
</table>

3.2.2 Mapping out the stakeholders within the fit-out supply chain

**Research task i:**
Map out the stakeholders within the fit-out supply chain.

**Methods description:**
Exploratory interviews were conducted using chain-referral (snowball) sampling, as shown in Figure 3.1. For this research task, seventeen people related to the fit-out industry were contacted and ten of them were interviewed. The interview data was cross-checked to lead to an objective interpretation. Key questions asked included, but were not limited to: what is
the general fit-out process in the UK? What is the general structure of the fit-out supply chain? Who are the stakeholders in this supply chain?

Figure 3.1 shows the route followed when searching for the stakeholders to interview, using chain-referral sampling. Each rectangle represents an actor or stakeholder: empty rectangles represent actors that were contacted while filled rectangles represent stakeholders that were interviewed. The figure only includes the people that were contacted to address research task \( i \) and not the totality of the people that were contacted or interviewed, which are reported below in Table 3.4. Personal and company names were anonymised throughout the thesis due to UCL data protection guidelines, as later mentioned in section 3.5.

![Figure 3.1: Route followed to find the corresponding interviewees for the initial stage (research task \( i \)), using chain-referral sampling. Filled rectangles represent stakeholders that were interviewed.](image)

### 3.2.3 Defining stakeholders’ and actors’ functions

**Research task ii:**
Define the function of actors/stakeholders across the stages in the fit-out process and define the relations among them. Evaluate their impact on the material flow.

**Methods description:**
a) Notes from interviews and personal communications (i.e. phone calls or emails) were qualitatively analysed using NVivo (2018). All interview data was divided into codes or categories as shown in Appendix B. In total, 28 interviews and personal communications (out of 31 available) were considered in the qualitative analysis, which were also used for research task \( vi \). A summary of the interviewees is given in Table 3.4, including policy makers, design teams, General Contractors, Waste Contractors, Waste Dealers and Reuse third parties, among other (see roles defined for the fit-out supply chain in subsection 4.2.1).
b) Onsite observations were used for defining the roles of the different fit-out supply-chain actors. Useful observations for this task were conducted during fit-out works and at meetings with design teams and General Contractor’s Site Managers.

### 3.2.4 Finding out key fit-out materials and components

**Research task iii:**
Determine the key materials and components that get installed and removed during the fit-out process and assess their environmental impact in terms of EC.

**Methods description:**

a) Questionnaires to Site Managers and Waste Contractors were conducted. During these questionnaires, subjects were asked (according to their experience) which are the building materials and components most commonly found in fit-out projects. An example of a questionnaire to Waste Contractors is shown in Appendix C, although in practice interviews with stakeholders were adapted to the context and circumstances.

b) Onsite observations were carried out before, during and after fit-out. An observational diary was used during fit-out case studies to register personal observations about the building materials and components. The observational diary is presented in Appendix D.

c) A PRA was performed if the circumstances allowed for it; two PRAs were carried out for the five fit-out case studies. Table 3.2 shows a template of the spreadsheet designed to carry out the PRAs.

<table>
<thead>
<tr>
<th>Table 3.2: Spreadsheet designed for PRAs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Table for recording PRA inventory in fit-out case studies.</td>
</tr>
<tr>
<td><strong>Item</strong></td>
</tr>
<tr>
<td>---------</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

(b) Quality scale.

<table>
<thead>
<tr>
<th>Quality</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor</td>
<td>P</td>
</tr>
<tr>
<td>Fair</td>
<td>F</td>
</tr>
<tr>
<td>Good</td>
<td>G</td>
</tr>
<tr>
<td>Excellent</td>
<td>E</td>
</tr>
</tbody>
</table>

(b) Destination options.

<table>
<thead>
<tr>
<th>Destination</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retained</td>
<td>RET</td>
</tr>
<tr>
<td>Reused Onsite</td>
<td>RON</td>
</tr>
<tr>
<td>Reused Offsite</td>
<td>ROF</td>
</tr>
<tr>
<td>Stored</td>
<td>STO</td>
</tr>
<tr>
<td>Taken by Waste Contractor</td>
<td>WC</td>
</tr>
</tbody>
</table>

The ‘item’ refers to the building component or material (e.g. window blinds, ceiling tile, plasterboard). The corresponding ‘code’ for each type of building component or material is given in Table 3.3. The ‘quantity’ is the amount of the item and can be given in units, metres or square metres depending on the item. There is a ‘quality’ associated which each item and can range from P: poor, F: fair, G: good, and E: excellent. The ‘EC’ is given in kgCO₂eq for
the production stage (raw material supply, transport to manufacturer and manufacturing) of each item. Values for EC were obtained from declared global warming potential in EPDs for similar products to those found in PRAs, so this analysis was conducted for indicative purposes only (as later mentioned in section 3.6); i.e. to identify the building components that may account for the highest EC. In some instances, several EPDs were averaged for a single product to reduce uncertainty, as shown in Appendix E.

Table 3.3: Codes for each building component and material commonly found at office and HEI fit-outs.
An item is considered ‘poor’ when no longer performs as it should, ‘fair’ when it performs correctly but has short remaining lifespan or shows some damage, ‘good’ when the item only shows some superficial or aesthetic deterioration, and ‘excellent’ when it is in perfect condition or appears to have negligible deterioration. ‘Destination’ refers to the path followed by the item after being removed, e.g. the item can be reused or collected by a Waste Contractor. ‘Waste stream’ covers the type of waste the item falls into, according to the common waste categories used by Waste Contractors (see section 2.5.3). Dimensions were previously considered as a field for the table but the disparity among the size of a certain building component made it unfeasible to present it.

Table 3.3 presents the corresponding codes for each component and material commonly found at office and HEI fit-outs. The two letters in the codes stand for the category of fit-out layer, as follows: ‘AP’ for appliances, ‘CL’ for internal cladding, ‘FI’ for finishes, ‘FU’ for furniture, ‘IN’ for insulation, ‘KI’ for kitchen-related items, ‘LI’ for lighting-related items, ‘OP’ for openings (doors and windows), ‘SI’ for signage, ‘SE’ for services, ‘ST’ for infill structure, and ‘TO’ for toilet-related items. The numbers in the codes are assigned according to the items’ alphabetical order.

### 3.2.5 Identifying key waste streams generated during fit-out

**Research task iv:**
Identify the key waste streams generated in the fit-out process and measure them.

**Methods description:**

a) In a similar fashion as research task iii, onsite observations were conducted during fit-out works followed by an analysis of the observational diary.

b) For the fit-out case studies where the Site Manager provided a SWMP and the Waste Manager provided a Waste Report, these were cross-examined and taken as a reference to show the amounts of different waste streams that were generated during a certain fit-out project.

c) A set of parameters were used for measuring and comparing waste arisings in fit-out case studies. These parameters are defined as follows:

- **GFA \([m^2]\):** internal gross floor area of the fit-out project.
- **Waste \([t]\):** waste generated during the fit-out project.
- **RWG \([t/100m^2\) of GFA]:** the rate of waste generation results from dividing the waste generated by the project’s GFA and then multiplying by a factor of 100.
- **ROWS [%]:** the ratio of onsite waste segregation represents the proportion of segregated waste, relative to the total waste generation in fit-out project.

### 3.2.6 Tracing paths and final destinations of waste streams

**Research task v:**
Trace paths and final destinations of wastes from fit-out case studies.

**Methods description:**

a) Structured interviews with Waste Contractors, (staff in charge of) MRFs and waste final destinations were conducted either in person, via phone call, or email. Waste Contractors
were asked about the types and amounts of waste streams they commonly collect, the collection and sorting process, and where they deliver the different waste streams for onward segregation or recycling. The staff at MRFs were asked what they do with the waste streams they receive or where they send them to. The waste streams' paths were followed or enquired after to the greatest possible extent.

b) An MFA was elaborated using the SankeyMATIC (2018) online tool for three of the case studies analysed. To register the necessary information for the MFA, Table 0.8 in Appendix F was used to record the waste streams for a particular case study. The table also recorded the share or percentage attributable to that waste stream, whether the waste stream was reclaimed by the Waste Contractor for subsequent reuse, the intermediary (i.e. Waste Dealer or MRF) used by the Waste Contractor, and the different destinations that each waste stream may follow.

3.2.7 Identifying incentives, mechanisms and barriers for fit-out circularity

Research task vi:
Here the aim was twofold, firstly to identify the key incentives that encourage decision makers to pursue higher rates of (closed-loop) recycling and reuse of building components and materials while recognising the current and potential measures and procedures that support it. Secondly, this task aimed to identify the barriers that hinder circularity in the fit-out industry.

Methods description:
a) A literature review was used for this research task. The literature analysed covered the relationship between the circular economy and building fit-outs, touching on the sustainability of building products, building design criteria, supply chains and logistics, business models, waste management, and assessment methods, \textit{inter alia}.

b) The qualitative analysis of interviews (as described in research task \textit{ii} was also used for identifying incentives, mechanisms and barriers for material circularity. c) Lastly, observations made during fit-out case studies were useful to the findings.

3.3 Research outline

3.3.1 Summary of research design
Figure 3.2 illustrates the research design to offer a clearer perspective of the overall research structure. The research tasks and methods system are aligned with the main research objective. Qualitative and quantitative approaches provided different types of data, which were analysed separately and synthesised in the discussion. Conclusions and recommendations are also aligned with the research objective.
### 3.3.2 Outline of stakeholder interviews

Table 3.4 presents a summary of the stakeholders who provided relevant information throughout all the stages of the project, including a total of 31 persons. Each row in the table corresponds to a different person that was interviewed or contacted. The stakeholders are ordered and coded according to the date they were contacted. The column showing the ‘company’s activity’ provides a broad idea of the business’ or organisation’s economic activity. The ‘position at company’ provides the role that stakeholders have at the respective company. The field ‘actor in fit-out supply chain’ relates to the stakeholder’s role in the fit-out supply chain (as seen in Figure 4.2). The ‘date’ corresponds to the date of the first meeting with the corresponding stakeholder, although in some cases subsequent meetings were conducted.
Table 3.4: Summary of interviewed or contacted stakeholders who provided relevant information to the project. Stakeholders are ordered chronologically according to the date in which they were contacted.

<table>
<thead>
<tr>
<th>Code</th>
<th>Company’s activity</th>
<th>Position at company</th>
<th>Actor in fit-out supply chain</th>
<th>Date [dd/mm/yyyy]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Interior design</td>
<td>Design and Sustainability Director</td>
<td>Policy maker</td>
<td>07/11/2015</td>
</tr>
<tr>
<td>2</td>
<td>Higher education</td>
<td>Senior researcher</td>
<td>Researcher</td>
<td>07/11/2015</td>
</tr>
<tr>
<td>3</td>
<td>Engineering and project management services</td>
<td>Senior Material Consultant</td>
<td>Supplier</td>
<td>27/11/2015</td>
</tr>
<tr>
<td>4</td>
<td>Professional accreditation (RICS)</td>
<td>Certification Development Manager</td>
<td>Assessment method developer</td>
<td>23/01/2016</td>
</tr>
<tr>
<td>5</td>
<td>Freecycling/sharing platform (online)</td>
<td>Owner and Director</td>
<td>Reuse third party</td>
<td>12/05/2016</td>
</tr>
<tr>
<td>6</td>
<td>Waste management</td>
<td>Strategic Environmental Manager</td>
<td>Waste Dealer</td>
<td>28/06/2016</td>
</tr>
<tr>
<td>7</td>
<td>Waste management and consulting</td>
<td>Owner and Director</td>
<td>Waste Contractor</td>
<td>29/06/2016</td>
</tr>
<tr>
<td>8</td>
<td>Higher education</td>
<td>Sustainability Officer</td>
<td>Client</td>
<td>22/08/2016</td>
</tr>
<tr>
<td>9</td>
<td>Building fit-out</td>
<td>UK Development and Expansion Lead</td>
<td>General Contractor</td>
<td>13/09/2016</td>
</tr>
<tr>
<td>10</td>
<td>Building fit-out</td>
<td>Environmental and Sustainability Manager</td>
<td>General Contractor</td>
<td>27/09/2016</td>
</tr>
<tr>
<td>11</td>
<td>Carbon profiling</td>
<td>Carbon Consultant</td>
<td>Design Team</td>
<td>15/10/2016</td>
</tr>
<tr>
<td>12</td>
<td>Waste management</td>
<td>Quality, Resource and Development Manager</td>
<td>Waste Contractor</td>
<td>19/10/2016</td>
</tr>
<tr>
<td>13</td>
<td>Waste management</td>
<td>Senior Sustainability Manager</td>
<td>Waste Contractor</td>
<td>21/10/2016</td>
</tr>
<tr>
<td>14</td>
<td>Building fit-out</td>
<td>S.H.E.Q. Manager</td>
<td>General Contractor</td>
<td>16/11/2016</td>
</tr>
<tr>
<td>15</td>
<td>Building fit-out</td>
<td>Site Manager</td>
<td>General Contractor</td>
<td>08/12/2016</td>
</tr>
<tr>
<td>16</td>
<td>Building sustainability, health and wellbeing</td>
<td>Sustainability Consultant</td>
<td>Design Team</td>
<td>21/05/2017</td>
</tr>
<tr>
<td>17</td>
<td>Waste recycling</td>
<td>Quality Manager</td>
<td>Final destination</td>
<td>08/06/2017</td>
</tr>
<tr>
<td>18</td>
<td>Waste recycling</td>
<td>Supplier Coordinator</td>
<td>Final destination</td>
<td>10/06/2017</td>
</tr>
<tr>
<td>19</td>
<td>Waste recycling</td>
<td>Sales Manager</td>
<td>Final destination</td>
<td>15/06/2017</td>
</tr>
<tr>
<td>20</td>
<td>Waste recycling</td>
<td>Sales Representative</td>
<td>Final destination</td>
<td>15/06/2017</td>
</tr>
<tr>
<td>21</td>
<td>Waste management</td>
<td>Service Supplier Coordinator</td>
<td>Waste Dealer</td>
<td>19/06/2017</td>
</tr>
<tr>
<td>22</td>
<td>Higher education</td>
<td>Building Sustainability Manager</td>
<td>Client</td>
<td>22/07/2017</td>
</tr>
<tr>
<td>23</td>
<td>Building fit-out</td>
<td>Site Manager</td>
<td>General Contractor</td>
<td>19/09/2017</td>
</tr>
</tbody>
</table>
Certain interviewees from the listed earlier (see Table 3.4) were related to case studies presented in this work. Table 3.5 shows the number and types of interviewees contacted from each of the two Waste Contractors analysed, along with the subsection number in which the case studies are presented. Both Waste Contractors specialise in C&D waste. Waste Contractor 1 was employed in four of the fit-out case studies analysed, so the information given by this actor was relevant to developing MFAs for fit-out case studies. This Waste Contractor (1) provided aggregated data for the waste they collect yearly (see subsection 4.3.2), and they also supplied Waste Reports for the waste collected in each of the fit-out case studies.

<table>
<thead>
<tr>
<th>Code</th>
<th>Company’s activity</th>
<th>Position at company</th>
<th>Actor in fit-out supply chain</th>
<th>Date [dd/mm/yyyy]</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>Building works and demolition services</td>
<td>Site Manager</td>
<td>Strip-out Contractor</td>
<td>21/09/2017</td>
</tr>
<tr>
<td>25</td>
<td>Higher education</td>
<td>Estates Strategy Manager</td>
<td>N/A</td>
<td>05/10/2017</td>
</tr>
<tr>
<td>26</td>
<td>Construction logistics</td>
<td>Senior Logistics Manager</td>
<td>N/A</td>
<td>26/10/2017</td>
</tr>
<tr>
<td>27</td>
<td>Higher education</td>
<td>Waste Manager</td>
<td>N/A</td>
<td>15/11/2017</td>
</tr>
<tr>
<td>28</td>
<td>Furniture, equipment and material reuse platform (online)</td>
<td>Co-founder</td>
<td>Reuse third party</td>
<td>04/12/2017</td>
</tr>
<tr>
<td>29</td>
<td>Building components and material reuse platform (online)</td>
<td>Head of Costumer Service</td>
<td>Reuse third party</td>
<td>05/12/2017</td>
</tr>
<tr>
<td>30</td>
<td>Building demolition services</td>
<td>Quality and Resource Manager</td>
<td>Strip-out Contractor</td>
<td>11/12/2017</td>
</tr>
<tr>
<td>31</td>
<td>Building works and demolition services</td>
<td>Resource Manager</td>
<td>Strip-out Contractor</td>
<td>14/12/2017</td>
</tr>
</tbody>
</table>

Table 3.5: Number and types of interviewees contacted from each Waste Contractor.

<table>
<thead>
<tr>
<th>Waste Contractors</th>
<th>Number of interviewees</th>
<th>Types of interviewee</th>
<th>Subsection number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste Contractor 1 (related to fit-out case studies)</td>
<td>1</td>
<td>Waste Contractor’s Senior Sustainability Manager</td>
<td>4.3.2</td>
</tr>
<tr>
<td>Waste Contractor 2 (unrelated to fit-out case studies)</td>
<td>1</td>
<td>Waste Contractor’s Quality &amp; Resource Development Manager</td>
<td>4.3.3</td>
</tr>
</tbody>
</table>

Table 3.6 indicates the number and types of interviewees contacted for each of the fit-out case studies, along with the subsection number in which the case studies are presented. For the fit-out case studies where an MFA was conducted (subsections 4.4.3, 4.4.4 and 4.4.5), other downstream supply-chain stakeholders were contacted (through personal communications) apart from the Waste Contractor. These included a staff member within a Waste Dealer as well as staff members within the respective final destinations.
### 3.3.3 Outline of fit-out case studies

The fit-out case studies were selected through chain-referral sampling. Involvement with UCL Sustainability Officer at the early stages of this work, allowed the author to timely engage in two UCL fit-out projects. UCL is a major client for the General Contractor in charge of the Bank offices fit-out (pilot study), and through a referral from UCL Sustainability Officer, the author was partly involved in the Bank offices project. UKGBC offices came into play as the Sustainability Consultant was in touch with the main supervisor of this PhD project. It’s worth mentioning that the General Contractor and Waste Contractor involved in the UKGBC project turned out to be the same ones employed in the two UCL case studies. Finally, involvement with the Conduit Members’ Club fit-out was possible through referral from this PhD project’s main supervisor, as he was in contact with this fit-out’s Sustainability Consultant (who was a different person than the Sustainability Consultant involved in the UKGBC fit-out).

In terms of scope, the involvement with fit-out projects covered both the de-fit and re-fit stages, except for the Bank offices case study in which only the re-fit stage was considered. Case study timeframes were limited to the duration of the corresponding fit-out project. Only the outflow of building materials (waste) was under the scope. The inflow was not included in this study as the fate of newly installed building products is uncertain, and end of life pathways for these products would only be known in the future.

Table 3.7 presents a summary of the analysed fit-out case studies including the name of the ‘case study’, ‘space type’, ‘location’, ‘GFA’, ‘cost’, and whether the case study included a ‘de-fit’, ‘re-fit’, ‘PRA’ or ‘MFA’. Where information for a certain case study was not available, the legend ‘N/A’ is used.
### Table 3.7: Summary of the analysed fit-out case studies.

<table>
<thead>
<tr>
<th>Case study</th>
<th>Space type</th>
<th>Location</th>
<th>GFA [m²]</th>
<th>Cost [£]</th>
<th>De-fit</th>
<th>Re-fit</th>
<th>PRA</th>
<th>MFA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bank offices</td>
<td>office</td>
<td>Canary Wharf</td>
<td>1,550</td>
<td>1.7m</td>
<td>no</td>
<td>yes</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>UKGBC offices</td>
<td>office</td>
<td>Bloomsbury</td>
<td>162</td>
<td>60k</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>UCL Confucius Institute</td>
<td>office and teaching</td>
<td>Bloomsbury</td>
<td>290</td>
<td>866k</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Conduit Members’ Club</td>
<td>restaurant, hotel, meeting</td>
<td>Mayfair</td>
<td>1,720</td>
<td>N/A</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>UCL Central House</td>
<td>study and teaching</td>
<td>Bloomsbury</td>
<td>269</td>
<td>N/A</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>

#### 3.4 Mixed-methods approach

Mixed methods research involves the use of both qualitative and quantitative data in a research project (Halcomb and Hickman, 2015). It is an approach to knowledge that deliberately considers multiple viewpoints, emphasising on the insight that can be gained by “thinking dialectically” and engaging multiple research paradigms (Creamer, 2015).

Qualitative and quantitative research tend to be associated with different types of research questions or different aspects of a research problem (Brannen, 1992; Creamer, 2015). These research approaches are commonly distinguished in the data collection stage, where data in qualitative research tend to be words, while data in quantitative research tend to be numbers (Creamer, 2015); however, this differentiation can be overly simplistic (Brannen, 2005). The association of qualitative research with an inductive logic and quantitative research with theoretical deduction can often be reversed in practice since both types of research may use both forms of logic (Brannen, 2005).

Generally, qualitative research “looks through a wide lens”, searching for patterns of interrelationships between previously unspecified concepts, while the quantitative researcher “looks through a narrow lens” at a specified set of variables (Brannen, 1992). The two research paradigms have led to two research tendencies, where qualitative research seeks deep, rich observational data and quantitative methods pursue hard, generalizable findings (Johnson and Onwuegbuzie, 2004).

Qualitative research involves an interpretive approach and employs a variety of empirical materials, such as personal experiences, interviews and observational texts (Murray, 2003). This approach can effectively conduct cross-case comparison and describe phenomena in rich detail, although the results from qualitative research can be influenced by the researcher’s personal biases (Johnson and Onwuegbuzie, 2004).
Quantitative methods, on the other hand, tend to be based on numerical measurements of specific aspects of phenomena, abstracting from particular findings to seek generalizable results (Murray, 2003). This approach is effective for theory testing, and it is also useful for obtaining data that allow quantitative predictions. However, quantitative methods may omit collateral insights due to the focus on theory (or hypothesis) testing, and knowledge produced from these methods may be too abstract (Johnson and Onwuegbuzie, 2004).

Through the combination of both qualitative and quantitative approaches, mixed method research aims to complement their strengths and to avoid overlapping their weaknesses (Johnson and Onwuegbuzie, 2004). Multi-method research is not necessarily better research, but it is rather an approach used to address the variety of research questions, which may lead to the use of different research methods (Brannen, 2005).

For instance, where the research issue requires unambiguous answers (e.g. measuring material flows), a quantitative method such as a questionnaire may be appropriate. Conversely, where the questions to respondents may result in complex, discursive replies (e.g. defining stakeholders’ interaction in the supply chain), qualitative techniques such as in-depth interviews may better suited (Brannen, 1992).

3.5 Data protection and risk assessment

Potential interviewees were firstly contacted via email (as shown in Appendix G) and a few of them by phone call. A brief of the project (see Appendix G) was given to all contacted stakeholders explaining the purpose of the research and how the provided information would be used and managed. Most interviews were conducted personally and some of them via email or phone. Interviewers were asked for their consent, either verbally when interviews were carried out both personally or by phone, or in a written form when interviews took place through email. Some of the data collected accounted for commercially sensitive information. According to UCL data protection guidelines, personal and company names were not disclosed in the research project.

It was resolved that no risk assessment was required for the PhD project since negligible risk was involved due to the nature of the fit-out activity. The author would go on site prior to the fit-out process, during the soft-strip stages, which represented negligible risk, and after the fit-out process was finished. The author was not present in the stage of building works which entailed stripping of structural components. Appropriate measures were selected to prevent any remaining potential risk. The author would wear personal protection equipment (PPE) on site as appropriate and as directed by any site manager and customary safety precautions were taken. Other activities during the research project consisted of interviews to be carried out in safe environments, such as offices.

3.6 Limitations of the study

3.6.1 Summary of research limitations

The present study posed contextual and methodological limitations, which highlight the need for further research on building fit-outs. Table 3.8 provides an overview of the study limitations, as well as their impact on the study and the corresponding mitigation measures.
proposed or implemented. The following sections provide more detail on each of these limitations. Despite these limitations, this study offers valuable insights in an area where relatively little research has been done.

<table>
<thead>
<tr>
<th>Aspect of study</th>
<th>Limitation</th>
<th>Impact on study</th>
<th>Mitigation measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Literature review</td>
<td>Little prior research on the topic</td>
<td>No extensive knowledge foundation</td>
<td>Exploratory research design</td>
</tr>
<tr>
<td>Research design</td>
<td>Focus on material flows</td>
<td>Financial value of flows excluded</td>
<td>Future research suggested</td>
</tr>
<tr>
<td>Research design</td>
<td>Only outflows considered</td>
<td>New components installed during re-fit are not part of the MFA</td>
<td>Future research suggested</td>
</tr>
<tr>
<td>Research design</td>
<td>Critical materials disregarded</td>
<td>No quantification of critical materials mass or financial value</td>
<td>Future research suggested</td>
</tr>
<tr>
<td>Data collection</td>
<td>Small, London-based sample</td>
<td>Quantitative results are indicative only</td>
<td>Future research suggested</td>
</tr>
<tr>
<td>Data collection</td>
<td>Chain-referral sampling</td>
<td>Limited access to stakeholders</td>
<td>Author needed to be persistent</td>
</tr>
<tr>
<td>Data collection</td>
<td>Lack of available, reliable data</td>
<td>Quantitative data is based on interviewers’ responses</td>
<td>Cross-examination of data</td>
</tr>
</tbody>
</table>

3.6.2 Literature review

There is little prior research conducted on building fit-outs and thus this work lacks an extensive knowledge foundation. The research was designed in an exploratory fashion to define the key variables in the analysis. For instance, the structure of the supply-chain and the definition of the stakeholders (involved in fit-out processes) might have been the type of information that could be obtained from secondary sources. However, this information was not available in the literature and exploratory interviews were conducted through chain-referral sampling to address this research question. This work aims to provide a knowledge background on the subject, where new opportunities for further research and practical research tools were identified.

3.6.3 Research design

The analysis of fit-out case studies was conducted within a relatively short timeframe. The research investigates outflowing materials that were formerly installed in the building site. Newly installed building products were not part of the MFAs in this work since their eventual end-of-life stage is an uncertain event taking place in the future. In an analogy with fluid mechanics the approach of this work is Lagrangian rather than Eulerian, as it aims to follow a specific set of materials from the building site to their respective final destinations, rather than analysing the flow of materials in a specific location. Also, the effects of fit-out on the social or economic value of the respective buildings or spaces was out of scope.

Mass was the main measuring variable, while volume and the financial value of material flows were not considered in the study. EC were quantified for two of the fit-out case studies based
on EPDs, which are not fully standardised and were selected for similar products to those found in fit-outs, but not the exact same ones. EC results are thus given for indicative purposes only. The material composition of building components was not analysed or measured. For instance, a carpet tile may be made up of several materials and to ascertain this composition would require an elemental analysis such as infrared spectroscopy (Curran, personal interview, 19 August 2016). Alternatively, this information could be assumed from secondary sources, such as EPDs, but these are only available for a limited range of products. LCA databases, such as Ecoinvent (2019), often do not include some of the substances specified in EPDs. Accordingly, there is no discussion on critical materials such as phosphorous in fluorescent lamps or silicon in WEEE.

Nonetheless, this study identified key building fit-out materials and components as well as the main waste streams generated during fit-out processes. Future work can be supported on these findings to conduct LCAs for the most common or problematic (e.g. difficult to treat at end of life) building fit-out products. As well, the MFAs conducted in this study provide insight into the final destinations of waste, which can offer practical LCA scenarios for the disposal stage of products.

3.6.4 Data collection
The author was involved in eight fit-out case studies and some of them could not be effectively analysed and no useful data could be obtained from them. Barriers to better involvement included incompatibility with the timeframes of the fit-out projects and slow or ineffective communication from the corresponding stakeholders. The findings of this work are thus based on the involvement with five fit-out case studies and on a set of interviewed stakeholders. The study does not cover a comprehensive sample of the UCL building portfolio or fit-out practices in London, and size of the study sample does not allow to draw robust statistical inferences, as shown in section 5.4. However, some findings are indicative for the non-domestic fit-out industry in the UK, the European Union, and for a global scale to some extent.

The methodological approach encountered some barriers as several stakeholders were reluctant to participate or to provide comprehensive information, and the author often needed to chase stakeholders or be persistent until useful information was provided. For instance, it took about a year to persuade one of the Waste Contractors to provide useful data about the paths and destinations of the waste they handle. To accomplish this, the Waste Contractor’s Senior Sustainability Manager was contacted through two references, and the author needed to keep insisting or reminding the manager to finally obtain the corresponding information.

Moreover, constraints at the building sites implied that the author had limited time and opportunities to make onsite observations. General Contractors’ staff generally seemed to be uncomfortable about an outsider looking at their operation, and site visits were most of the times guided by Site Managers, so the author relied on the availability of the respective Site Manager.

There was also a time constraint for interviews since most stakeholders are busy people with little time to spare. The author was thus required to be as concise and effective as possible while interviewing people. However, some variables or aspects to study were only identified
after analysing interview data, so the author often had to get back to interviewers to enquire on these aspects. Interviewees were generally helpful, but they seemed to get annoyed when contacted more than twice, and sometimes politely asked the author to stop contacting them as they were busy.

Although interviews and questionnaires were mostly conducted through chain-referral sampling, it was required to contact several stakeholders outside this scheme. When stakeholders were contacted directly, without a formal reference, they generally seemed less cooperative to answer questions.

Quantitative data for waste generation and treatment was provided by the stakeholders involved in the fit-out case studies. As later discussed in sections 5.3 and 5.4, this information was not necessarily accurate, and it generally was not as comprehensive as the author expected, which was a major limitation of this work. For instance, material losses throughout the waste-management supply chain were not reported, and most of the information provided for waste final destinations did not precisely state the recycling output of waste, or the locations where final treatments took place. As a mitigation measure, data provided by different stakeholders was cross-examined when possible or pertinent, and waste streams’ paths were followed or enquired after to the greatest possible extent.
4 Results

4.1 Introduction to results
This chapter presents the results from the methodological approach laid out in the previous chapter. Firstly, the definition of the supply-chain structure and the involved stakeholders are introduced in section 4.2, as this helps better understand the subsequent sections. Section 4.3 covers the results for Waste Contractor case studies, section 4.4 provides detailed findings from the fit-out case studies, and section 4.5 presents more general issues encountered in UCL fit-outs.

4.2 Initial investigation of the fit-out supply chain

4.2.1 Supply chain structure and stakeholder roles
In this work, the term fit-out includes the de-fit and re-fit stages, i.e. the whole refurbishment process. The term de-fit is defined here as the process of removing interior fittings, fixtures, and finishes, while re-fit is the process of installing these interior building materials and components.

Stakeholders within the fit-out supply chain were interviewed including policy makers and stakeholders collaborating in the Design Team, as well as Fit-out Contractors, Waste Contractors and employees in recycling facilities, these were selected by chain referral sampling (see Chapter 3). From these interviews, it was concluded that the variety of fit-out processes encountered in the area of study are very similar to each other. Therefore, a generic office and HEI fit-out supply chain can be determined and described.

Figure 4.1 shows the generic structure of the fit-out supply chain derived from discussions with stakeholders. The decision flow is represented in the diagram with an orange arrow and the material flow is represented with a green arrow. It can be appreciated that both the decision and the material flows have a linear tendency, as further discussed in subsection 5.2.1. The decision flow is determined by who assigns whom in the supply chain; for instance, the Client assigns the Design Team, who in turn appoints the General Contractor and so on. The material flow is determined by how material or waste moves across different supply-chain stakeholders, which is explained as follows. Material is provided by Suppliers and delivered to the Building Site. The General Contractor will hand to the Waste Contractor the waste from the Building site, including removed components from de-fit and material offcuts from re-fit. When a Strip-out Contractor is employed, this actor will oversee the de-fit process, and they will be the ones delivering components removed in the Building Site to the Waste Contractor. The Waste Contractor(s) will then deliver the different waste streams to several Waste Dealers, and lastly material will be taken to the respective final destinations (as further explained at the end of this section).

The supply-chain actors shown in Figure 4.1 are defined for this work as follows.

- **Client**: person or organisation who wishes to have a fit-out and provides a payment to the corresponding stakeholders for this service.
- **Design Team**: set of professionals who meet with the Client to design a fit-out project brief.
- **Supplier**: company that produces and sells the building products to be used (manufacturer) or the company that distributes these products to the user (distributor).
- **General Contractor**: main fit-out contractor, generally in charge of all onsite operations.
- **Strip-out Contractor**: secondary fit-out contractor, in charge of onsite operations only during the de-fit stage.
- **Waste Contractor**: company in charge of collecting the waste and transporting it to a waste Transfer Site.
- **Waste Dealer**: company which buys (generally) smaller amounts of segregated or unsegregated waste to then sell larger amounts of segregated waste to other companies.
- **Final destination**: the last location where material or waste is sent to follow its final end-of-life treatment.

The supply chain for a specific fit-out project is generally formed in the following way: the Client decides to undertake a fit-out, then chooses the boundaries. They need to decide whether sustainability is a key requirement and what level is required, as well as whether to use a particular assessment method as a guideline. The Client also hires the Design Team, which is usually comprised of an Architect, Project Manager(s), M&E Engineer(s), Quantity Surveyor(s), and sometimes includes a Sustainability Consultant.

Once the project brief is developed by the Design Team (including project specifications, times and budget), the Project Manager sends out an invitation to tender. The invitation to tender (also known as Request for Tender) is commonly sent to prospective contractors (Select Tender), but it can also take the form of an Open Tender which is done by public advertisement. Any Fit-out Contractor can then submit a tender, i.e. offer their services to
carry out the fit-out works, stating how they would perform the job and how much it would cost. The tendering process should not be biased so the offer that best meets the requirements outlined in the Tender Package and provides the best value for money should get the contract. The Fit-out Contractor who gets the job will be known as the General Contractor and will be in charge of all the onsite processes and they may sub-contract other actors, such as the Strip-out Contractor (also known as Demolition Contractor) or Waste Contractor. Likewise, the General Contractor normally has within their team another Project Manager, M&E Engineer, Quantity Surveyor and a Sustainability Manager. Both the Design Team and the General Contractor may decide on the specification of building materials and components which are provided by the Suppliers (comprised by manufacturers and distributors).

The assigned Waste Contractor will be in charge of collecting the waste arising from the de-fit and re-fit stages to then take the waste to a Transfer Site, where it usually gets sorted into different waste streams. The different waste streams are then sent out to different specialised MRFs where each waste stream is aggregated; each MRF may deal with one or several different waste streams. In this work MRFs are also referred to as Waste Dealers. The respective MRFs or Waste Dealers further sort and grade the waste streams for onward delivery, potentially to their respective final destinations. These destinations may include recycling within the original industry (closed-loop) or in another industry (cascade), as well as incineration for energy recovery or landfill.

### 4.2.2 Stakeholder interviews contextualised in the fit-out supply chain

Figure 4.2 shows the stakeholders or actors that were contacted, represented by circled numbers. Each of these numbers relate to a person that was contacted (31 in total), as shown in Table 3.4. The circled numbers (or persons contacted) are superimposed on the supply-chain stakeholders they belong to.

Additionally, the diagram is divided into **Foreground** and **Background** stakeholders, where the **Foreground** stakeholders are directly involved in the fit-out or waste management process, while the **Background** stakeholders are merely involved in the overarching fit-out industry.

As can be seen, three stakeholders in the **Background** supply chain were contacted, including a Policy maker, a fit-out Assessment method developer and a Researcher with expertise in the topic. Within the **Foreground** the supply chain, contacted stakeholders comprised two Clients, two Design Teams, one Supplier, five General Contractors, three Strip-out Contractors, three Reuse third parties, three Waste Contractors, two Waste Dealers and four members of staff in waste final destinations.

A different General Contractor was contacted on five instances, while it was not possible to contact EA staff. As presented in subsection 2.4.6, the EA, sponsored by DEFRA, is the body in charge of the regulation of management and treatment of waste. Despite several attempts to contact staff in this organisation, there was no response from them, and no interviews were able to take place.
4.3 Case studies of Waste Contractors in fit-out

4.3.1 Involved Waste Contractors

Two major Waste Contractors in London were contacted to identify the key material or waste streams generated during fit-out projects. It was found that Waste Contractors generally break down all C&D waste into a few waste streams or categories: glass, mixed waste, gypsum, hardcore, metals, paper & cardboard, plastic, textiles, WEEE, and wood. Tables are presented below showing the shares or proportions of waste streams by mass, relative to the overall waste collection for each of the Waste Contractors. For both cases, data was obtained from the Waste Contractor’s Waste Report.

4.3.2 Case study: Waste Contractor 1

Waste Contractor 1 is one of the largest of its kind (by amount of waste collected) in the London area and was employed at four of the fit-out case studies analysed, partly due to this contractor’s market dominance. This Waste Contractor provided bulk data for the waste they collect yearly (see Table 4.1), and they also supplied specific Waste Reports for the waste collected in each of the fit-out case studies, which was relevant to developing the corresponding MFAs. Breakdown of mixed waste in fit-out case studies was based on this Waste Contractor bulk data.

Waste Contractor 1 collects or receives most types of C&D waste, so figures are given for the overall waste collected and not only for fit-out waste. Data provided below was obtained
from an interview with the Waste Contractor’s Senior Sustainability Manager (personal interview, 21 October 2016). Table 4.1 presents the main collected waste streams, along with the respective EWC code and the share or percentage by mass for each waste stream collected, estimated yearly for 2016.

Table 4.1: Share for each waste stream collected. Estimated yearly figure for 2016 (Waste Report from Waste Contractor 1, 2017).

<table>
<thead>
<tr>
<th>Waste stream</th>
<th>EWC code</th>
<th>Share [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixed waste</td>
<td>17 09 04</td>
<td>72.0</td>
</tr>
<tr>
<td>Wood (including fibreboard)</td>
<td>17 02 01</td>
<td>13.0</td>
</tr>
<tr>
<td>Plasterboard</td>
<td>17 08 02</td>
<td>5.0</td>
</tr>
<tr>
<td>RAF</td>
<td>N/A</td>
<td>4.0</td>
</tr>
<tr>
<td>Hardcore</td>
<td>17 01 07</td>
<td>2.0</td>
</tr>
<tr>
<td>Metals</td>
<td>17 04 01</td>
<td>2.0</td>
</tr>
<tr>
<td>Glass</td>
<td>17 02 02</td>
<td>&lt;1.0</td>
</tr>
<tr>
<td>Insulation</td>
<td>17 06 04</td>
<td>&lt;1.0</td>
</tr>
<tr>
<td>Paper &amp; Cardboard</td>
<td>20 01 01</td>
<td>&lt;1.0</td>
</tr>
<tr>
<td>Plastic</td>
<td>17 02 03</td>
<td>&lt;1.0</td>
</tr>
<tr>
<td>Textiles</td>
<td>20 01 11</td>
<td>&lt;1.0</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

1 Metals also include EWC codes 17 04 02 to 17 04 06.

As can be appreciated, mixed waste accounted for the largest share of the annual waste collected, and there is a significant difference between this share and that of the second-ranked waste stream. This waste contractor segregates most of their mixed waste at their Transfer Site, but the breakdown of this mixed waste was not reported. Other important waste streams (accounting for large share) are wood and plasterboard. It is worth pointing out that waste RAF ranked within the top-five waste streams collected by this Waste Contractor.

4.3.3 **Case study: Waste Contractor 2**

Waste Contractor 2 specialises in building fit-out waste; over 90% of the waste they collect comes from fit-outs. Data provided below was obtained from an interview with the Waste Contractor’s Quality & Resource Development Manager (personal interview, 26 May 2017). Table 4.2 shows the mass and the share (by mass) for each material stream relative to the overall waste collection, for the first quartile of 2017.

As can be seen, plasterboard and mixed waste accounted for the largest shares of the waste collected during the reported period. Mixed waste is not segregated in this Waste Contractor’s Transfer Site so it is passed on as mixed waste to Waste Dealers (MRFs). Metals and wood also constituted a significant share of the waste collected by Waste Contractor 2.
Table 4.2: Mass and share for each material stream collected, for the first quarter of 2017 (Waste Report from Waste Contractor 2, 2017).

<table>
<thead>
<tr>
<th>Waste stream</th>
<th>EWC code</th>
<th>Mass [t]</th>
<th>Share [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plasterboard</td>
<td>17 08 02</td>
<td>72.59</td>
<td>31.8</td>
</tr>
<tr>
<td>Mixed waste</td>
<td>17 09 04</td>
<td>66.25</td>
<td>29.0</td>
</tr>
<tr>
<td>Metals</td>
<td>17 04 01</td>
<td>32.84</td>
<td>14.4</td>
</tr>
<tr>
<td>Wood (including fibreboard)</td>
<td>17 02 01</td>
<td>25.06</td>
<td>11.0</td>
</tr>
<tr>
<td>Glass</td>
<td>17 02 02</td>
<td>13.02</td>
<td>5.7</td>
</tr>
<tr>
<td>Hardcore</td>
<td>17 01 07</td>
<td>11.90</td>
<td>5.2</td>
</tr>
<tr>
<td>Paper &amp; Cardboard</td>
<td>20 01 01</td>
<td>6.18</td>
<td>2.7</td>
</tr>
<tr>
<td>WEEE</td>
<td>20 01 36</td>
<td>0.32</td>
<td>0.1</td>
</tr>
<tr>
<td>Fluorescent lamps</td>
<td>20 01 21</td>
<td>0.30</td>
<td>0.1</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td><strong>228.46</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

1 Metals also include EWC codes 17 04 02 to 17 04 06.

4.4 Case studies of building fit-out

4.4.1 Summary of fit-out case studies

Table 4.3 presents a summary of the analysed fit-out case studies including the name of the ‘case study’, ‘space type’, ‘certification used’, ‘GFA’, ‘waste’ generated, ‘RWG’, and ‘ROWS’. Where information for a certain case study was not available, the legend ‘N/A’ is used.

Table 4.3: Summary of fit-out case studies, showing the respective RWG and ROWS.

<table>
<thead>
<tr>
<th>Case study</th>
<th>Space type</th>
<th>Certification used</th>
<th>GFA [m²]</th>
<th>Waste [t]</th>
<th>RWG [t/100m²]</th>
<th>ROWS [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bank offices</td>
<td>office</td>
<td>SKA Offices: Gold</td>
<td>1,550</td>
<td>37.30¹</td>
<td>2.41</td>
<td>76</td>
</tr>
<tr>
<td>UKGBC offices</td>
<td>office</td>
<td>none</td>
<td>162</td>
<td>3.81</td>
<td>2.35</td>
<td>69</td>
</tr>
<tr>
<td>UCL Confucius Institute</td>
<td>office and teaching</td>
<td>SKA Offices: Gold</td>
<td>290</td>
<td>35.28</td>
<td>12.17</td>
<td>79</td>
</tr>
<tr>
<td>UCL Central House</td>
<td>study and teaching</td>
<td>SKA HEI: Gold</td>
<td>269</td>
<td>6.38</td>
<td>2.37</td>
<td>26</td>
</tr>
<tr>
<td>Conduit Members' Club</td>
<td>restaurant, hotel, meeting</td>
<td>none</td>
<td>1,720</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

¹ Waste generated at the Banks offices fit-out accounts only for the re-fit stage.

4.4.2 Case study: Bank offices

4.4.2.1 Description

This fit-out project accommodated office space for an international bank branch, and it was certified as Gold through the SKA Rating Offices scheme. The fit-out project took place within five floors of a building located in Canary Wharf, accounting for a GFA of 1,550 m² and a project value of £1.7m. The fit-out started in July 2015 and was estimated to continue for two years, although there was no involvement throughout the completion of the project. This office fit-out was the first project analysed and represented the pilot case study. In this
case, the de-fit process was finished prior to (the author’s) involvement and only the re-fit process was analysed. An MFA was conducted for this fit-out project and is presented below. The quantitative findings were not integrated with the results of the other case studies as this pilot study was not representative of a full fit-out process.

The information for this case study was provided by the General Contractor’s Environmental and Sustainability Manager (personal interview, 27 September 2016) and the Waste Contractor’s Senior Sustainability Manager (personal interview, 21 October 2016 and 05 June 2017).

4.4.2.2 Supply chain structure

The supply-chain stakeholders and structure for the Bank offices fit-out are described and presented according to data given in a personal interview with the General Contractor’s Environment and Sustainability Manager. Figure 4.3 shows the supply-chain stakeholders and structure. The Client assigned a Design Team to oversee the whole project design which was compiled in the Tender Package. The Design Team included actors such a Project Manager, an Architect, M&E Engineers and a Quantity Surveyor. The Design Team appointed a General Contractor to be in charge of all the works on site. The Suppliers were selected by both the Design Team and the General Contractor. The Waste Contractor was subcontracted by the General Contractor and determined the Waste Dealers, and the latter chose the respective final destinations of waste.

![Supply-chain structure](image)

Figure 4.3: Supply-chain structure showing the decision flow and communication links, for the Bank offices fit-out (personal interview, 2016).

As can be appreciated from Figure 4.3, the communication in the supply chain took place only between adjacent stakeholders, i.e. only between stakeholders that appear next to each other in the diagram. The Design Team was the supply-chain actor with the most communication links, as they were in communication with the Client, the Suppliers, the General Contractor and the Strip-out Contractor.
4.4.2.3 *Fit-out procedure*

The Strip-out Contractor and the General Contractor were respectively appointed by the Design Team. When the General Contractor arrived at the Building Site, the de-fit process was already finished and the fit-out was in a Cat A stage (see subsection 2.3.2 for detail on fit-out categories). The fit-out procedure is not presented for this case study due to the lack of involvement with the onsite process during the fit-out project.

Figure 4.4: Waste generation during the re-fit stage at the Bank offices fit-out, including: (a) Plasterboard off-cuts. (b) Removed HVAC components. Mixed waste containing, among other materials, (c) a wood palette, metal stud frame and cabling; (d) stone floor tile offcuts, fibreboard and insulation; (e) cabling, insulation and paper; (f) particleboard and metal stud frame. (g) 1,100L wheelie bins containing cardboard packaging and (h) other mixed waste. (All photos copyright of the authors unless otherwise stated).
Figure 4.4 shows photographs taken on site during the re-fit stage at the Bank offices fit-out. Some of the types of waste generated include: plasterboard offcuts (picture a), which accounted for a large share of the total waste generated; HVAC metal components (picture b) removed to re-fit most of the HVAC system; and mixed waste containing offcuts of metal stud frame, stone floor tiles, insulation, wood (fibreboard and particleboard) and cabling (pictures c-f). Pictures g and b show the 1,100-litre wheelie bins used during the re-fit process and provided by the corresponding Waste Contractor, containing cardboard packaging and other mixed waste.

4.4.2.4 **Pre-refurbishment audit**

The PRA was not considered for this case study due to the lack of involvement with the onsite procedure prior to the fit-out project.

4.4.2.5 **Material flow analysis**

This subsection presents the amounts (by mass) of the waste streams generated during the re-fit process and aims to identify the paths and final destinations for each waste stream. The data presented here is based on the fit-out SWMP and discussions with the Waste Contractor’s Senior Sustainability Manager.

The waste generated during the re-fit stage accounted for 37.3 tonnes [t], with a landfill diversion rate of 99.5%. The RWG for the re-fit stage was 2.41 t/100 m² of GFA. Table 4.4 shows a breakdown of the waste streams generated during the re-fit process.

<table>
<thead>
<tr>
<th>Item</th>
<th>Mass [t]</th>
<th>Recycled [t]</th>
<th>Disposed [t]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Re-fit waste</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cardboard</td>
<td>0.10</td>
<td>0.10</td>
<td>0.00</td>
</tr>
<tr>
<td>Insulation</td>
<td>0.20</td>
<td>0.20</td>
<td>0.00</td>
</tr>
<tr>
<td>Hardcore</td>
<td>2.00</td>
<td>2.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Metals</td>
<td>4.70</td>
<td>4.70</td>
<td>0.00</td>
</tr>
<tr>
<td>Mixed waste</td>
<td>8.80</td>
<td>8.62</td>
<td>0.18</td>
</tr>
<tr>
<td>Paper</td>
<td>1.60</td>
<td>1.60</td>
<td>0.00</td>
</tr>
<tr>
<td>Plasterboard</td>
<td>16.10</td>
<td>16.10</td>
<td>0.00</td>
</tr>
<tr>
<td>Plastics</td>
<td>0.40</td>
<td>0.40</td>
<td>0.00</td>
</tr>
<tr>
<td>Wood</td>
<td>3.40</td>
<td>3.40</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>Total [t]</strong></td>
<td><strong>37.30</strong></td>
<td><strong>37.12</strong></td>
<td><strong>0.18</strong></td>
</tr>
<tr>
<td>Percentage [%]</td>
<td>100</td>
<td>99.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Figure 4.5 presents a bar chart showing the percentages or shares (by mass) of each waste stream relative to the overall waste collection, during re-fit stage. The ROWS represented 76%, relative to the waste generated during the re-fit stage. For this case study, plasterboard accounted for the largest share by mass (43%) of the overall waste collected.

Figure 4.6 shows the path of the material and components followed throughout the different locations. Building products were firstly provided by Suppliers and taken to the Building Site where they were installed and subsequently removed. When material and components were
removed, these were considered and treated as waste, so they were taken to a waste Transfer Site (by the Waste Contractor) to be segregated. After segregation, different waste streams were transported to the corresponding MRFs before being sent to the corresponding final destinations. This path is the same for four of the fit-out case studies, while for Conduit Members’ Club an alternative path was followed (as seen in Figure 4.39).

Figure 4.5: Percentage (by mass) for each material stream relative to the total waste generation, during the re-fit stage, for the Bank offices fit-out (fit-out SWMP, 2016).

Figure 4.6: Material flow throughout the corresponding locations, for the Bank offices fit-out (personal interviews, 2016).

Figure 4.7 shows a Sankey diagram of the flow of the respective waste streams across the supply chain for the Bank offices fit-out. Waste Contractor 1 was used for this case study, so proportions of mixed waste were broken down into different waste streams according to this contractor’s waste-stream shares (see subsection 4.3.2). Apart from the Waste Contractor, other downstream supply-chain stakeholders were contacted, including a staff member within a Waste Dealer (Service Supplier Coordinator, 19 June 2017) and final destinations (Quality Manager, 08 June 2017; Supplier Coordinator, 10 June 2017; Sales Manager, 15 June 2017; Sales Representative, 15 June 2017).

It is worth pointing out that the MFAs conducted in this work are based on data provided by the involved stakeholders, and precise data was enquired after to the greatest possible extent. As later discussed in sections 5.3 and 5.6, there is room for uncertainty in these MFAs and in the UK waste-management regulatory system. For instance, material losses during transportation, sorting and recycling of waste are not reported by any of the involved stakeholders.
The Waste Contractor employed in these case studies reported no RDF going out from their Transfer site. However, another Waste Contractor (not involved in these case studies) was later contacted and stated that out of the total C&D waste they receive yearly, 15% goes out as RDF as a result of waste collection and sorting processes (Waste Contractor’s Managing Director, personal communication, 15 January 2021). In the case-study MFAs presented here, further waste sorting took place down the supply chain at MRFs and final destinations which likely resulted in material losses, but the Waste Contractor stated this was not reported to them by downstream suppliers.

Out of the total waste generation, over 99% was reported as recycled. Apart from recycling or downcycling, other final destinations included recovery alternatives such as composting (3.22 t) and energy recovery through incineration (2.87 t). Recycled waste streams were split into multiple recycling destinations that generally require a lower grade of material quality, except for 60% of the plasterboard (9.66 t), which was delivered by the Waste Dealer (MRF) to the Supplier and turned into new plasterboard. Therefore, around 25% of material was closed-loop recycled out of the 37.3 t of waste generated during the fit-out process. Plasterboard was the only waste stream that showed some percentage of closed-loop recycling, driven by UK regulations for gypsum-based products. Less than 1% (0.18 t) of the total waste was landfilled. From information given by the Waste Contractor and other downstream stakeholders, the waste wood was sent to Belgium, metals ended up in Spain or Turkey (depending on the offered price at the time), and plastics were sent to China, while all other final destinations were located within the UK. In total, around 42% (15.79 t) of waste was exported abroad.
4.4.3 Case study: UKGBC offices

4.4.3.1 Description

This fit-out project was conducted for the UK Green Building Council (UKGBC) offices within the Building Centre and took place in the area of Bloomsbury from August to October 2016. The fit-out GFA was 162 m$^2$ and the project value was £60k. No certification scheme was pursued as the Client and the Design Team did not consider it convenient for the relatively small scale of the project. However, this fit-out project reported one of the lowest RWGs in the UK as seen below in subsection 4.4.3.3. Table 4.8 shows a photograph of the UKGBC office fit-out.

The information for this case study was provided by the Design Team’s Sustainability Consultant (personal interview, 04 August 2016 and 14 October 2016) and the General Contractor’s Environment and Sustainability Manager (personal interview, 05 October 2016).

![Figure 4.8: Completed fit-out at the UKGBC offices (image source: http://bit.ly/2ho44wf).](http://bit.ly/2ho44wf)

4.4.3.2 Supply chain structure

The supply-chain stakeholders and structure for the UKGBC offices fit-out are described and presented according to data given in personal interviews. To define the project’s supply chain, the Design Team’s Sustainability Consultant and the General Contractor’s Environment and Sustainability Manager were interviewed.

Figure 4.9 shows the supply-chain stakeholders and structure. The Client assigned a Design Team to be in charge of the whole project design which was compiled in the Tender Package. The Design Team comprised actors from different firms respectively; namely, a Project Manager, an Architect, M&E Engineers, a Quantity Surveyor and a Sustainability Consultant. The Design Team appointed a General Contractor to be in charge of all the works on site. The Suppliers were selected mainly by the Design Team. The Waste Contractor was subcontracted by the General Contractor to be in charge of the collection of waste on site, and the Waste Contractor determined different Waste Dealers for different waste streams. Finally, the respective final destinations were established by the Waste Dealers. As can be
appreciated, the communication in the supply chain took place only between adjacent stakeholders. The Design Team was the supply-chain actor with the most communication links, as they were in communication with the Client, the Suppliers and the General Contractor.

Figure 4.9: Supply-chain structure showing the decision flow and communication links, for the UKGBC offices fit-out (personal interviews, 2016).

4.4.3.3 **Fit-out procedure**
The fit-out procedure was not considered for this case study due to the lack of involvement with the onsite procedure during the fit-out project.

4.4.3.4 **Pre-refurbishment audit**
The PRA was not considered for this case study due to the lack of involvement with the onsite procedure prior to the fit-out project.

4.4.3.5 **Material flow analysis**
This subsection presents the amounts (by mass) of the waste streams generated during the fit-out process and aims to identify the paths and final destinations for each waste stream. The data presented here is based on the fit-out SWMP and discussions with key stakeholders in the fit-out waste management process.

The total waste generated, considering de-fit (2.82 t) and re-fit (0.99 t), was 3.81 t, with a landfill diversion rate of 99% for both cases. The RWG was 2.35 t/100 m\(^2\) of GFA, which is 63% lower than the reported UK average for offices (6.4 t/100 m\(^2\) GFA, see subsection 2.5.1).

Table 4.5 shows a breakdown of the waste streams generated during the fit-out project. The waste during the de-fit stage (2.82 t) accounted for 74% of the total waste generated. The waste streams from the re-fit stage (0.99 t) comprised 26% of the total waste (3.81 t). In this case, plasterboard waste mainly constituted offcuts.

Figure 4.10 presents a bar chart showing the percentages or shares (by mass) of each waste stream relative to the overall waste collection, during the de-fit and re-fit stages. The ROWS
represented 69% of total waste arisings. For this case study, plasterboard accounted for the largest share by mass (44%) of the overall waste collected.

Table 4.5: Waste generated during the UKGBC offices fit-out (fit-out SWMP, 2016). ‘Recycled’ accounts for waste sent to Waste Contractor and ‘disposed’ accounts for waste sent to landfill.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>De-fit waste</td>
<td>Re-fit waste</td>
<td>All waste</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mixed waste</td>
<td>0.90</td>
<td>0.88</td>
<td>0.27</td>
<td>0.26</td>
<td>1.17</td>
<td>1.14</td>
<td>0.03</td>
</tr>
<tr>
<td>Insulation</td>
<td>0.20</td>
<td>0.20</td>
<td>-</td>
<td>-</td>
<td>0.20</td>
<td>0.20</td>
<td>0</td>
</tr>
<tr>
<td>Office furniture</td>
<td>0.28</td>
<td>0.28</td>
<td>-</td>
<td>-</td>
<td>0.28</td>
<td>0.28</td>
<td>0</td>
</tr>
<tr>
<td>Plasterboard</td>
<td>0.96</td>
<td>0.96</td>
<td>0.72</td>
<td>0.72</td>
<td>1.68</td>
<td>1.68</td>
<td>0</td>
</tr>
<tr>
<td>Wood</td>
<td>0.48</td>
<td>0.48</td>
<td>0.72</td>
<td>0.72</td>
<td>0.48</td>
<td>0.48</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total [t]</strong></td>
<td>2.82</td>
<td>2.80</td>
<td><strong>0.99</strong></td>
<td><strong>0.98</strong></td>
<td><strong>3.81</strong></td>
<td><strong>3.78</strong></td>
<td><strong>0.03</strong></td>
</tr>
<tr>
<td><strong>Percentage [%]</strong></td>
<td>100</td>
<td>99</td>
<td><strong>100</strong></td>
<td><strong>99</strong></td>
<td><strong>100</strong></td>
<td><strong>99</strong></td>
<td>1</td>
</tr>
</tbody>
</table>

Figure 4.10: Percentage (by mass) for each material stream relative to the total waste generation, during both the de-fit and re-fit stages, for the UKGBC offices fit-out (fit-out SWMP, 2016).

Figure 4.11 shows a Sankey diagram of the flow of the respective waste streams across the supply chain for the UKGBC offices fit-out. Waste Contractor 1 was also employed in this case study, so proportions of mixed waste were broken down into different waste streams according to this contractor’s waste-stream shares (see subsection 4.3.2). Apart from the Waste Contractor, other downstream supply-chain stakeholders were contacted, including a staff member within a Waste Dealer (Service Supplier Coordinator, 19 June 2017) and final destinations (Quality Manager, 08 June 2017; Supplier Coordinator, 10 June 2017; Sales Manager, 15 June 2017; Sales Representative, 15 June 2017). Office furniture was broken down into the respective waste streams according to Waste Contractor’s assumptions.

Out of 3.81 t of waste generated, 99% was reported as recycled, where 0.34 t was composted, 0.24 t was incinerated for energy recovery, and 1 t (of plasterboard) was closed-loop recycled. In total, 1.33 t (35%) of waste were exported abroad.
4.4.4 Case study: UCL Confucius Institute

4.4.4.1 Description

This fit-out project aimed to turn formerly unused space into multi-use space for the teaching of Chinese language and culture, as part of the UCL Institute of Education. The Confucius Institute fit-out took place between December 2016 and June 2017, with a project value of £866k, and was certified as SKA Gold using the Offices scheme. The building, built in 1847, is located in Bloomsbury and belongs to UCL Estates. It comprises four stories plus a basement, which result in a total GFA of 290 m². Figure 4.12 illustrates the completed fit-out project at UCL Confucius Institute. Figure 4.13 shows the floor plans for the lower ground before fit-out (plan a) and after the proposed fit-out (plan b).

The information for this case study was provided by the Client’s (UCL) Sustainability Officer (personal interview, 12 January 2016, 24 November 2016 and 03 May 2017), the General Contractor’s Site Manager (personal interview, 24 November 2016, 09 December 2016 and 11 April 2017; personal communication, 15 December 2017) and the Waste Contractor’s Senior Sustainability Manager (personal interview, 21 October 2016 and 05 June 2017).
4.4.4.2 Supply chain structure

The supply-chain stakeholders and structure for the UCL Confucius Institute fit-out are described and presented according to data given in personal interviews. For this case study, different supply-chain actors were interviewed: the Client’s (UCL) Sustainability Officer, the General Contractor’s Site Manager, and the Waste Contractor’s Senior Sustainability Manager.

Figure 4.14 shows the supply-chain stakeholders and structure. The Client was represented by a UCL Stakeholder, a UCL Project Manager and the UCL Sustainability Officer. The Client assigned a Design Team to be in charge of the whole project design which was compiled in the Tender Package. The Design Team comprised actors from different firms respectively; namely, a Project Manager (also known as External Project Manager), an Architect, a M&E Consultant, and a Quantity Surveyor. The Design Team appointed a General Contractor to be in charge of the works on site, and the General Contractor, in turn, appointed a Strip-out Contractor to carry out the de-fit stage. The Suppliers were selected by both the Design Team and the General Contractor, as some building components and materials were originally specified by the Design Team and the General Contractor changed some of the specified components and added new ones. The Waste Contractor, subcontracted by the General Contractor, was used for both the de-fit and re-fit stages. However, the Strip-out Contractor hired a Waste Carrier to deliver the waste to the Waste Contractor’s Transfer Site. On the other hand, the re-fit waste was collected by the Waste Contractor themselves. The Waste Contractor determined different Waste Dealers for different waste streams. Finally, the respective final destinations were established by the Waste Dealers.

The Client and the Design Team had the higher influence in the decision making through the design stage, while the General Contractor showed higher influence during the de-fit and re-fit stages, as further discussed in subsection 5.2.1. The General Contractor was the supply-chain actor with the most communication links in this case study, and the communication in the supply chain took place only between adjacent stakeholders.
Figure 4.13: Floor plan for the UCL Confucius Institute lower ground (a) before fit-out and (b) after proposed fit-out [scale 1:50] (Design Team, 2017).
4.4.4.3 Fit-out procedure

The procedures shown below for the UCL Confucius Institute fit-out were obtained from interviews or personal communications with the Client’s (UCL) Sustainability Officer, the General Contractor’s Site Manager and the Waste Contractor’s Senior Sustainability Manager.

De-fit stage

The de-fit stage was performed by the Strip-out Contractor and comprised the removal of building components following the sequence below:

1. Removal of hazardous elements, namely, asbestos. These elements were found on the first floor as doors’ cladding panels. The asbestos panels were removed and sent to a specialised centre in Essex to get buried in a specialised landfill.
2. The second step was the ‘soft-strip’, which includes any element that is not structural. In this case, soft-strip included elements such as blinds, cupboards, counter, sink, vinyl flooring, carpet tiles and carpet plywood, electrical cabling, doors, and boiler, among other. This stage was carried out by a sub-contractor specialised in strip-outs (the Strip-out Contractor).
3. ‘Building works’ was the third stage in this fit-out project. Building works relate to any structural element, such as load-bearing or non-load-bearing walls, partitions, stud framing or columns. This stage was carried out by the General Contractor.

Re-fit stage

The re-fit was conducted by the General Contractor and included the following steps:
1. Polishing of floorboards. Floorboards (formerly under the carpet tiles) were retained in situ and sanded using a specialised sanding machine. Figure 4.17 shows the floorboards before (picture b) and after sanding (picture c). About 6% of the floorboards were replaced with new timber as these were worn out.

2. Openings in retained partitions. Timber-stud plasterboard partitions were retained on the second and third floor. These partitions were modified by creating an aperture to connect the adjacent rooms, as shown Figure 4.20.

3. Dry lining of all internal walls. Plasterboard was applied, taped at the joints and sealed.

4. Fitting of electrical and network cabling.

5. Application of wall finish, which in this case was paint.

6. Installations of toilets and kitchen equipment.

7. Replacement of staircase handrail, which was originally intended to be retained due to heritage criteria, but it was finally replaced due to aesthetic considerations. The reasons for this are reviewed further in Chapter 5.

8. Installation of light fittings, electrical sockets and fire alarms.

9. Installation of doors and window blinds.

**Waste collection**

The process for waste collection was similar for both the de-fit and the re-fit process. The de-fit process was carried out by the Strip-out Contractor, and they employed a licensed Waste Carrier to deliver the waste to the Waste Contractor (subcontracted by the General Contractor). The re-fit process was performed by the General Contractor and the re-fit waste was collected by the same Waste Contractor and taken to their Transfer Site. The procedure shown below was compiled with data obtained from the General Contractor’s Site Manager and the Waste Contractor’s Senior Sustainability Manager.

1. Wheelie bins were placed on the site, usually with a capacity of 360 L. The bins were provided by the Waste Contractor (Figure 4.15). Bins were colour coded according to the type of waste stream as follows: blue for metals, black for mixed waste, brown for cardboard and paper, green for wood, red for plastic and yellow/white for plasterboard.

2. Waste was put into the bins. Waste was not fully segregated during the de-fit stage since the General Contractor did not require waste segregation as the scale of the project was too small to make segregation cost-effective. The General Contractor could not specify at which project scale waste segregation does become cost-effective. During the re-fit stage, more care was put into waste segregation yielding a higher ratio of segregated waste than mixed waste.

3. A compactor or caged vehicle from the Waste Carrier or Waste Contractor, respectively, came by the building’s main entrance and the bins’ contents were loaded into the compactor. During the de-fit stage, the Strip-out Contractor hired a third-party Waste Carrier to deliver the waste to the Waste Contractor for seven visits, as the Strip-out Contractor did not hold a waste-carrier license. Hazardous waste (asbestos) was delivered to an Authorised Treatment Facility (ATF) on two occasions by a spe-
cialist carrier. During the re-fit stage, waste was collected by the same Waste Contractor (themselves) on five occasions. When waste was segregated, different waste streams were kept apart in the vehicle using different cages.

4. Finally, the waste was taken to the Waste Contractor’s Transfer Site. The paths and final destinations of the waste are presented in subsection 4.4.4.5.

Figure 4.15: Wheelie bins, with a capacity of 360L, provided by Waste Contractor for the UCL Confucius Institute fit-out. Bins are colour coded according to type of waste stream.

4.4.4.4 Pre-refurbishment audit

A PRA was carried out by the author for this case study. Table 4.6 presents the PRA inventory for the Confucius Institute fit-out case study. The PRA includes the ‘item’ (building component), ‘code’ (specific for each item type – see Table 3.3), ‘quantity’ (number of items, metres or square metres), ‘quality’ (condition of the item as detailed in subsection 3.2.4), ‘destination’ (where it was taken), ‘waste stream’ (material stream it corresponds to) and ‘EC’ associated with the production of each item.

Table 4.6: PRA inventory for UCL Confucius Institute fit-out (author generated).
## Results

<table>
<thead>
<tr>
<th>Item</th>
<th>Code</th>
<th>Quantity</th>
<th>Quality</th>
<th>Destination</th>
<th>Waste stream</th>
<th>EC [kgCO₂ eq]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floorboards [m²]</td>
<td>CL 03</td>
<td>218</td>
<td>G</td>
<td>206 RET/12 WC</td>
<td>wood</td>
<td>224</td>
</tr>
<tr>
<td>Floor finish: vinyl [m²]</td>
<td>FI 04</td>
<td>5</td>
<td>P</td>
<td>WC</td>
<td>plastic</td>
<td>29</td>
</tr>
<tr>
<td>Kitchen counter [m]</td>
<td>KI 01</td>
<td>6</td>
<td>E</td>
<td>WC</td>
<td>wood</td>
<td>N/A</td>
</tr>
<tr>
<td>Kitchen cupboards</td>
<td>KI 02</td>
<td>14</td>
<td>E</td>
<td>WC</td>
<td>wood</td>
<td>N/A</td>
</tr>
<tr>
<td>Kitchen sink</td>
<td>KI 03</td>
<td>2</td>
<td>G</td>
<td>WC</td>
<td>metal</td>
<td>328</td>
</tr>
<tr>
<td>Light fitting</td>
<td>LI 01</td>
<td>30</td>
<td>E</td>
<td>WC</td>
<td>metal</td>
<td>4050</td>
</tr>
<tr>
<td>Light: fluorescent</td>
<td>LI 02</td>
<td>64</td>
<td>G</td>
<td>WC</td>
<td>glass/metal</td>
<td>941</td>
</tr>
<tr>
<td>Partition: plasterboard</td>
<td>ST 02</td>
<td>4</td>
<td>F</td>
<td>2 RET/2 WC</td>
<td>gypsum</td>
<td>29</td>
</tr>
<tr>
<td>Radiator</td>
<td>SE 11</td>
<td>17</td>
<td>P</td>
<td>WC</td>
<td>metal</td>
<td>1153</td>
</tr>
<tr>
<td>Shelves</td>
<td>FU 07</td>
<td>115</td>
<td>F</td>
<td>10 RON/105 WC</td>
<td>wood</td>
<td>N/A</td>
</tr>
<tr>
<td>Shelves rails</td>
<td>FU 07</td>
<td>24</td>
<td>E</td>
<td>WC</td>
<td>metal</td>
<td>N/A</td>
</tr>
<tr>
<td>Socket: electrical</td>
<td>SE 12</td>
<td>70</td>
<td>G/E</td>
<td>WC</td>
<td>metal/plastic</td>
<td>64</td>
</tr>
<tr>
<td>Socket: ethernet</td>
<td>SE 13</td>
<td>11</td>
<td>F</td>
<td>WC</td>
<td>metal/plastic</td>
<td>10</td>
</tr>
<tr>
<td>Stair case [steps]</td>
<td>ST 04</td>
<td>76</td>
<td>F</td>
<td>RET</td>
<td>timber</td>
<td>N/A</td>
</tr>
<tr>
<td>Stair handrail [m]</td>
<td>FI 07</td>
<td>8</td>
<td>E</td>
<td>WC</td>
<td>timber</td>
<td>N/A</td>
</tr>
<tr>
<td>Stairs nosing</td>
<td>FI 08</td>
<td>80</td>
<td>F</td>
<td>WC</td>
<td>plastic</td>
<td>N/A</td>
</tr>
<tr>
<td>Toilet bowl</td>
<td>TO 01</td>
<td>2</td>
<td>G</td>
<td>WC</td>
<td>ceramic</td>
<td>308</td>
</tr>
<tr>
<td>Toilet paper dispenser</td>
<td>TO 02</td>
<td>3</td>
<td>G</td>
<td>WC</td>
<td>plastic</td>
<td>N/A</td>
</tr>
<tr>
<td>Toilet sink</td>
<td>TO 05</td>
<td>3</td>
<td>G</td>
<td>WC</td>
<td>ceramic</td>
<td>199</td>
</tr>
<tr>
<td>Wall paper [m²]</td>
<td>FI 09</td>
<td>510</td>
<td>P</td>
<td>WC</td>
<td>wood/paper</td>
<td>2173</td>
</tr>
<tr>
<td>Wall tiles</td>
<td>FI 09</td>
<td>158</td>
<td>G</td>
<td>54 RET/104 WC</td>
<td>ceramic</td>
<td>22</td>
</tr>
<tr>
<td>Window blinds</td>
<td>OP 03</td>
<td>15</td>
<td>P</td>
<td>WC</td>
<td>plastic/textile</td>
<td>N/A</td>
</tr>
<tr>
<td>Window frame</td>
<td>OP 05</td>
<td>19</td>
<td>G</td>
<td>17 RET/2 WC</td>
<td>wood</td>
<td>2594</td>
</tr>
<tr>
<td>Window pane</td>
<td>OP 06</td>
<td>19</td>
<td>G</td>
<td>17 RET/2 WC</td>
<td>glass</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Quality</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor</td>
<td>P</td>
</tr>
<tr>
<td>Fair</td>
<td>F</td>
</tr>
<tr>
<td>Good</td>
<td>G</td>
</tr>
<tr>
<td>Excellent</td>
<td>E</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Destination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retained</td>
</tr>
<tr>
<td>Reused on site</td>
</tr>
<tr>
<td>Reused off site</td>
</tr>
<tr>
<td>Taken by Waste Contractor</td>
</tr>
</tbody>
</table>

As can be seen, most of the building components were taken by the Waste Contractor to be recycled (refer to subsection 4.4.3.3 to see waste streams paths and destinations). The building in question had been unused for a long time and a few existing components showed a poor condition; namely: fire alarms, vinyl flooring, radiators, wall paper and window blinds. However, there were many components in good condition that could have been retained or
Results

reused, thus saving energy and carbon emissions embodied in the new components. When interviewed, the site manager claimed that offsite reuse of components was negligible due to the lack of a market for reused building components (General Contractor’s Site Manager, personal interview, 11 Apr 2017). Accordingly, some components were sent to the Waste Contractor despite being in good or excellent condition, such as:

- two water boilers,
- 1,360 (218 m\(^2\)) carpet tiles (Figure 4.16, picture \(a\)),
- 218 m\(^2\) of (underlying) carpet plywood (picture \(a\)),
- six metres [m] of kitchen counter,
- 14 kitchen cupboards (picture \(b\)),
- 30 light fittings (picture \(c\)),
- 30 light fittings (picture \(c\)),
• 64 light tubes,
• 115 shelves (picture d),
• three sinks,
• two toilets (picture e),
• 70 electrical sockets (picture f).

On the other hand, some of the components were retained in situ, as follows:

• 36% of doors (saving 420 kgCO$_2$eq in doors and door frames),
• 72% of door frames (Figure 4.17, picture $a$),
• 94% of floorboards (pictures $b$ and $c$) (212 kgCO$_2$eq),
• 50% of partitions (14 kgCO$_2$eq),
• all the staircase steps,
• 34% of wall ceramic tiles (8 kgCO$_2$eq),
• 89% of window frames and panes (picture $d$) (2,321 kgCO$_2$eq).

Figure 4.17: Items retained in situ at UCL Confucius Institute fit-out: ($a$) door and door frame, ($b$) floorboards during sanding, ($c$) floorboards after sanding, and ($d$) window and window frame.

It’s worth mentioning that doors, partitions, staircase and windows were salvaged for heritage reasons. Elements that were reused offsite included:

• all the fire extinguishers,
• 9% of shelves.

It is a common belief that new building components and materials will lead to a more aesthetically pleasing interior space (UCL Waste Manager, personal interview, 15 November 2017). However, “old” items can easily blend or contrast with new components, creating a more pleasingly aesthetic space than if only new products were used. Figure 4.18 presents an example of an old item being retained and used along with the new components installed in the fit-out.
As shown in the picture, the wall ceramic tiles on the chimney were salvaged and retained, i.e. to be reused for the same purpose and in the same location. The ceramic tiles were probably around 60 years old and in a good condition, so they were carefully removed (picture a), stored, and re-positioned again (picture b) during the last stage of the fit-out. This resulted in a pleasant interior space which satisfactorily combines old and new elements.

Figure 4.19 shows a photograph after strip-out was done (picture a) and a picture showing the final outcome of the fit-out (picture b). It’s worth mentioning that picture a was taken from the ground floor, while picture b was taken from the second floor. It can be seen that all the staircase steps were renovated and retained. The staircase handrail was protected during the fit-out process as the original plan was to salvage it, but the Client finally chose to replace it due to aesthetic considerations (reviewed later in Chapter 5).

Figure 4.20 shows two of the internal partitions that were retained in the Confucius project and modified to fulfil the proposed layout design. One of the partitions was located on the second floor while the other was located on the third floor. These partitions were salvaged because of heritage criteria and not to save resources. In fact, when interviewed the Site Manager claimed it took more time and effort to salvage and adapt these elements than it would have taken to demolish them and build new partitions from scratch.

In this case study the barriers for reusing were twofold. On one hand, both Client and architect wished to install new components that matched their expectations so there was no encouragement to salvage the existing components. On the other hand, reusing components currently requires more time, space and planning. If components cannot be reused onsite, it can be complicated to find new users for the items in the right time frame.
Results

Figure 4.19: (a) Staircase during strip-out and (b) at the end of the fit-out, at UCL Confucius Institute fit-out.

Figure 4.20: Internal partitions retained for heritage criteria where openings were created to fulfil layout design, (a) on the second and (b) third floor, at UCL Confucius Institute fit-out.

It was observed that the lack of standardisation in building components also complicates the reuse rate at a large scale. For instance, Table 4.7 shows the disparity among the doors found before refurbishment. As can be seen, there were 22 doors in the building and only two of them had equal dimensions. This is also the case for items such as the counters or the cupboards which are tailored for a particular space.

EC in the PRA relates to the GHG emissions from the production stage of products and disregards the use phase (as specified in subsection 3.2.4). The total EC in the building products found on site prior to de-fit accounted for 18,403 kgCO₂eq. Out of this, 2,975 kgCO₂eq (16%) were saved due to items being retained or reused. The boiler was the building product with the highest EC per item, but only two boilers were found so these items only accounted for 2% of the total EC. The building components with the highest aggregated EC were light
fittings (which altogether accounted for 22% of the total EC), carpet tiles (17%) and wall paper (12%). It’s worth pointing out that these building components resulted in such high EC due to the number of items being removed, e.g. 30 light fittings, 1,360 carpet tiles a 518 m$^2$ of wall paper were found on site prior to de-fit. Retaining light fittings would have saved further 4,050 kgCO$_2$eq; however, this would not be practical in this case since removed light fittings were designed for fluorescent tubes, which were replaced with more efficient LED lighting. Most window (panes and frames) were retained in situ due to heritage protection requirements, which accounted for EC savings of 2,321 kgCO$_2$eq (13% of the total EC).

Table 4.7: Pre-refurbishment doors dimensions at UCL Confucius Institute fit-out (author generated).

<table>
<thead>
<tr>
<th>Lower Ground</th>
<th>Ground Floor</th>
<th>1st Floor</th>
<th>2nd Floor</th>
<th>3rd Floor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doors dimensions [cm]</td>
<td>Doors dimensions [cm]</td>
<td>Doors dimensions [cm]</td>
<td>Doors dimensions [cm]</td>
<td>Doors dimensions [cm]</td>
</tr>
<tr>
<td>81 x 200</td>
<td>88 x 211</td>
<td>94 x 213.5</td>
<td>82.5 x 202</td>
<td>75 x 190</td>
</tr>
<tr>
<td>82.5 x 195</td>
<td>94.5 x 211</td>
<td>88 x 213</td>
<td>73 x 202</td>
<td>78.5 x 199</td>
</tr>
<tr>
<td>77.5 x 197</td>
<td>72 x 183</td>
<td>73 x 202</td>
<td>83 x 190</td>
<td></td>
</tr>
<tr>
<td>77.5 x 201</td>
<td>72.5 x 185</td>
<td>83 x 201.5</td>
<td>72.5 x 199</td>
<td></td>
</tr>
<tr>
<td>74 x 199</td>
<td>77 x 197</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>77.5 x 201</td>
<td>73 x 199</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>74 x 199</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.4.4.5 Material flow analysis

This subsection presents the amounts (by mass) of the waste streams generated during the fit-out process and aims to identify the paths and final destinations for each waste stream. The data presented here is based on the fit-out SWMP and discussions with key stakeholders in the fit-out waste management process.

The total waste generated during this fit-out project (considering de-fit and re-fit) was 35.28 t, including 12.18 t for the de-fit stage, with a landfill diversion rate of 75%, and 23.10 t for the re-fit stage, where the landfill diversion rate was 99%. The average landfill diversion rate considering both stages was 91%, while the RWG was 12.17 t/100 m$^2$ of GFA.

Table 4.8 shows a breakdown of the waste streams generated during the fit-out project. Waste during the de-fit stage (12.18 t) accounted for 35% of the total waste generated. Waste streams from the re-fit stage (23.10 t) comprised 65% of the total waste (35.28 t). The re-fit waste in this case was higher than the de-fit waste, mainly because the space was unused and almost empty prior to fit-out.

Figure 4.21 presents a bar chart showing the percentages or shares (by mass) of each waste stream relative to the overall waste collection, during the de-fit and re-fit stages. The ROWS represented 79% of total waste arisings. For this case study, hardcore accounted for the largest share by mass (27%) of the overall waste collected.
Table 4.8: Waste generated during UCL Confucius Institute fit-out (fit-out SWMP, 2017). ‘Recycled’ accounts for waste sent to Waste Contractor and ‘disposed’ accounts for waste sent to landfill.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>De-fit waste</td>
<td>Re-fit waste</td>
<td>All waste</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asbestos</td>
<td>0.49</td>
<td>0</td>
<td>-</td>
<td>0.49</td>
<td>0</td>
<td>0.49</td>
<td></td>
</tr>
<tr>
<td>Hardcore</td>
<td>4.00</td>
<td>4.00</td>
<td>5.47</td>
<td>5.47</td>
<td>9.47</td>
<td>9.47</td>
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<tr>
<td>Mixed waste</td>
<td>7.32</td>
<td>4.76</td>
<td>-</td>
<td>7.32</td>
<td>4.76</td>
<td>2.56</td>
<td></td>
</tr>
<tr>
<td>Glass</td>
<td>0.37</td>
<td>0.37</td>
<td>1.02</td>
<td>1.02</td>
<td>1.39</td>
<td>1.39</td>
<td>0</td>
</tr>
<tr>
<td>Metals</td>
<td>-</td>
<td>-</td>
<td>2.49</td>
<td>2.49</td>
<td>2.49</td>
<td>2.49</td>
<td>0</td>
</tr>
<tr>
<td>Plasterboard</td>
<td>-</td>
<td>-</td>
<td>2.50</td>
<td>2.50</td>
<td>2.50</td>
<td>2.50</td>
<td>0</td>
</tr>
<tr>
<td>Plastics</td>
<td>-</td>
<td>-</td>
<td>1.61</td>
<td>1.61</td>
<td>1.61</td>
<td>1.61</td>
<td>0</td>
</tr>
<tr>
<td>Textiles</td>
<td>-</td>
<td>-</td>
<td>2.65</td>
<td>2.51</td>
<td>2.65</td>
<td>2.51</td>
<td>0.14</td>
</tr>
<tr>
<td>Wood</td>
<td>-</td>
<td>-</td>
<td>7.36</td>
<td>7.36</td>
<td>7.36</td>
<td>7.36</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total [t]</strong></td>
<td><strong>12.18</strong></td>
<td><strong>9.13</strong></td>
<td><strong>23.10</strong></td>
<td><strong>22.96</strong></td>
<td><strong>35.28</strong></td>
<td><strong>32.09</strong></td>
<td><strong>3.19</strong></td>
</tr>
<tr>
<td><strong>Percentage [%]</strong></td>
<td><strong>100</strong></td>
<td><strong>75</strong></td>
<td><strong>100</strong></td>
<td><strong>99</strong></td>
<td><strong>100</strong></td>
<td><strong>91</strong></td>
<td><strong>9</strong></td>
</tr>
</tbody>
</table>

Figure 4.21: Percentage (by mass) for each material stream relative to the total waste generation, during both the de-fit and re-fit stages for UCL Confucius Institute fit-out (fit-out SWMP, 2017).

Figure 4.22 shows the flow of the respective waste streams across the supply chain for UCL Confucius Institute fit-out. Waste Contractor 1 was employed in this case study, so proportions of mixed waste were broken down into the respective waste streams according to this contractor’s waste-stream shares (see subsection 4.3.2) and also based on onsite observations. Apart from the Waste Contractor, other downstream supply-chain stakeholders were contacted, including a staff member within a Waste Dealer (Service Supplier Coordinator, 19 June 2017) and final destinations (Quality Manager, 08 June 2017; Supplier Coordinator, 10 June 2017; Sales Manager, 15 June 2017; Sales Representative, 15 June 2017).

Out of 35.28 t of waste generated, 91% was reported as recycled, where 0.5 t was composted, 2.21 t were incinerated for energy recovery, and 1.5 t (of plasterboard) were closed-loop
recycled. Asbestos (0.49 t) were collected by a specialist contractor and sent to deep landfill burial. In total, 14.64 t (42%) of waste were exported abroad.

Figure 4.22: Waste-stream flows in tonnes [t], out of 35.28 t of waste, for UCL Confucius Institute fit-out (author generated).

4.4.5 Case study: UCL Central House

4.4.5.1 Description

The UCL Central House project took place from September to December 2017, turning 269 m² of office space into mixed study and lecture spaces. It was carried out on the east side of the second floor of Central House building, part of the UCL Estate. The 19th century building is located in the Bloomsbury area. This project was certified as SKA Gold using the HEI scheme. Figures below show the final outcome of the fit-out project, where the HUB/study space (Figure 4.23) and the teaching space (Figure 4.24) can be appreciated.

The information for this case study was provided by the Client’s (UCL) Sustainability Manager (personal communication, 23 October 2017), the General Contractor’s Site Manager (personal interview, 25 October 2017 and 07 December 2017) and the Strip-out Contractor’s Resource Manager (personal communication, 14 December 2017).

Figure 4.26 shows the floor plans for the entire floor before fit-out (plan a) and after fit-out (plan b). The shaded area in the floor plans indicates the space in the floor that was not included in the fit-out project.
4.4.5.2 Supply chain structure

The supply-chain stakeholders and structure for the UCL Central House fit-out are described and presented according to data given in personal interviews. For this purpose, the Client’s (UCL) Sustainability and the Strip-out Contractor’s Resource Manager were contacted.

Figure 4.25 shows the supply-chain stakeholders and structure. The Client was represented by a UCL Stakeholder, a UCL Project Manager and the UCL Sustainability Manager. The Client assigned a Design Team to be in charge of the whole project design which was compiled in the Tender Package. The Design Team comprised actors from different firms respectively; namely, a Project Manager (also known as External Project Manager), an Architect, a M&E Consultant, and a Quantity Surveyor. The Design Team appointed a General Contractor to be in charge of the works on site, and the General Contractor, in turn, appointed a Strip-out Contractor to carry out the de-fit stage. The Suppliers were selected by both the Design Team and the General Contractor, as some building components and materials were originally specified by the Design Team and the General Contractor changed.
some of the specified components and added new ones. The Waste Contractor was subcon-
ttracted by the General Contractor and was also used by the Strip-out Contractor. The Waste
Contractor determined different Waste Dealers for different waste streams. Finally, the re-
spective final destinations were established by the Waste Dealers.

As can be appreciated, the communication in the supply chain took place only between ad-
jacent stakeholders. The General Contractor was the supply-chain actor that with the most
communication links, as they were in communication with the Design Team, the Suppliers,
the Strip-out Contractor and the Waste Contractor.

4.4.5.3 **Fit-out procedure**

This subsection presents the procedure for the de-fit, re-fit and waste collection at UCL
Central House fit-out project. The procedures shown below were obtained from interviews
with the General Contractor’s Site Manager and personal observations throughout the fit-
out process.

Figure 4.27 presents different stages throughout the fit-out procedure (from a north-facing
angle) in the teaching space. Picture *a* shows the work space before the fit-out process started.
Picture *b* shows the space during re-fit: all office furniture was taken away, the ceiling tiles
and ceiling-tile rails were removed, as well as the HVAC ductwork and most of the cable
baskets. At a lower level, the carpet tiles were removed exposing the RAF. Picture *c* shows
the space after re-fit, where only the elements to be retained *in situ* were left in the building,
such as some of the HVAC cassettes and high-level cabling, as well as the RAF. At this point
the fit-out stage was something between shell & core and Cat A (see subsection 2.3.2). Pic-
ture *d* shows the final outcome of the fit-out; it can be appreciated that the high-level services
were left exposed.
Figure 4.26: Floor plan for the UCL Central House (a) before and (b) after fit-out [scale 1:100] (General Contractor, 2018).

Figure 4.28 also presents different stages throughout the fit-out procedure (from a south-facing angle) for the same space considered in the pictures above. Picture a shows the workspace before the fit-out process started. Picture b shows the space during re-fit: the ceiling tiles were removed but the ceiling-tile rails were still up, and the carpet tiles were gone. Picture c shows the process during re-fit. It can be seen that a retained HVAC cassette was being reinstalled and a new dry-lining partition was installed at the back. Picture d shows the final outcome of the fit-out. It can be appreciated that the original workspace was turned into a teaching space.
Figure 4.27: Fit-out procedure at UCL Central House (north-facing camera angle), showing the stages (a) before fit-out, (b) during de-fit, (c) after de-fit, and (d) after re-fit or final outcome.

Figure 4.28: Fit-out procedure at UCL Central House (south-facing camera angle), showing the stages (a) before fit-out, (b) during de-fit, (c) during re-fit, and (d) after re-fit or final outcome.

De-fit stage
The de-fit stage was performed by the Strip-out Contractor and involved the removal of the following building components, which are presented according to the order in which they were removed:

1. Office furniture, including workstations, chairs, lockers and shelves.
2. Floor finishes, which in this case only comprised carpet tiles.
3. Doors, including both glazed and wooden doors.
4. Ceiling tiles and insulation pads on top of them (Figure 4.29, picture a and b).
5. Light fittings and the respective fluorescent lamps.
6. Ceiling-tile rails (also known as metalwork) (picture b).
7. High-level services, including HVAC ductwork and cabling.
8. Raised-floor-to-ceiling partition walls (picture c), which are the internal partitions that were installed from the RAF to the ceiling.
9. Electrical sockets and floor outlets.
10. RAF (picture d). The RAF was retained in-situ, although it was temporarily removed for cleaning purposes and then re-installed again. The cleaning procedure was necessary as the cavity under the RAF served as a plenum to circulate fresh air (using an air-handling unit) that would come out through 36 grills installed in the RAF. Around 7% of the RAF tiles had to be replaced as they used to have floor outlets.
11. Slab-to-slab partition walls, which are the internal partitions that were installed from the floor slab to the ceiling slab.
12. Window blinds were left in-situ until they were replaced with the new ones. The Site Manager said these were left there because they did not obstruct the fit-out works.

**Figure 4.29:** UCL Central House fit-out: (a) Ceiling tile and insulation pad installed on top of it. (b) Ceiling tile while being removed. The ceiling-tile rails (metalwork) can be appreciated here. (c) Raised-floor-to-ceiling partition wall. (d) RAF, showing some floor outlets.

**Re-fit stage**

The re-fit stage was conducted by the General Contractor and comprised the maintenance or installation of the following building components, which are presented according to the order in which they were installed:

1. Underfloor cabling/services and maintenance work on RAF, including the following steps:
   a) Redundant services were removed.
b) New services were installed.
c) Concrete floor (underneath) was sealed so that it was free of dust.
d) RAF was re-installed.
e) RAF was levelled and de-rocked (removing any loose particles).

2. Acoustic spray on ceiling to improve the acoustic performance.

3. New partitions were installed for acoustic performance reasons, as the new space was designed as a teaching space. Where a new partition wall intersected with an “old” wall, the new one was inserted in the old one to prevent air flow and thus sound flow. Steel stud was used, with one plasterboard layer on the outside and three layers on the inside (where a final paint layer would be added) for acoustic purposes. The cavity was filled with mineral wool. Plasterboards were taped on the joints before being sealed.

4. The air-handling unit (AHU) was designed and procured as an entire unit, but it had to be broken down into parts to get it into the building. The AHU delivers fresh (or heated) air through the floor plenum (the cavity under the RAF), where air comes out through 36 grills installed on the floor. Stale air would be extracted though a larger grill on the south wall and taken back to the AHU. The AHU is connected to an outside inlet where fresh air comes in and an outlet where stale air goes out.

5. High-level cable trays/cabling and HVAC cassettes/ductwork. The high-level cabling and the cable trays that support it were installed on the ceiling through the acoustic layer and were left exposed, i.e. without a cladding layer such as ceiling tiles.

6. Wall finish, which in this case was paint. Three layers of paint were added on top of the sealer layer previously applied. The first two paint layers covered up the plasterboard properly. The last layer was done (afterwards) under the final lighting conditions once light fittings were installed, to ensure a high-quality finish.

7. Light fittings, electrical sockets, and fire alarms.

8. Floor finish (carpet tiles), doors, and window blinds.

**Waste collection**

The process for waste collection was the same for both the de-fit and the re-fit process. The de-fit process was carried out by the Strip-out Contractor, and they employed the Waste Contractor hired by the General Contractor to handle the waste generated at this stage. The re-fit process was performed by the General Contractor and the re-fit waste was collected by the subcontracted Waste Contractor. The procedure shown below was compiled with data obtained from the General Contractor’s Site Manager (personal interview, 07 December 2017) and the Strip-out Contractor’s Resource Manager (personal communication, 14 December 2017).

1. Wheelie bins were placed on the site, usually with a capacity of 660 L. The bins were provided by the Strip-out Contractor (Figure 4.30, picture a) and the Waste Contractor (picture b), respectively.
2. Waste was put into the bins. Usually waste was mixed in the bins with some exceptions in which a bin contained mainly one type of building component or material stream (e.g. plasterboard). Figure 4.31 shows wheelie bins containing mixed waste from the de-fit (pictures a and b) and re-fit (pictures c-f) stages.

Figure 4.30: Wheelie bins used by (a) Strip-out Contractor and (b) Waste Contractor at UCL Central House fit-out.

Figure 4.31: Mixed waste put into wheelie bins during fit-out at UCL Central House: (a) Mainly light fittings and ceiling tiles removed during de-fit. (b) Mixed components removed during re-fit. (c) Mainly plasterboard offcuts generated at re-fit. (d, e) Mixed offcuts generated at re-fit. (f) Mainly packaging from re-fit.
3. A compactor or caged vehicle came by the building’s back door and the bins’ contents were loaded into the compactor. Thus, the bins’ contents were mixed inside the compactor. Waste was collected by the Waste Contractor on 12 instances, while waste was delivered three times to the Waste Contractor’s facilities by a third-party waste carrier (Waste Contractor’s SWMP, 2017).

4. Finally, the waste was taken to a Transfer Site. The paths and final destinations of the waste are presented in subsection 4.4.5.5.

During this fit-out project, waste was not segregated as segregating was considered not cost-effective for a project of this relatively small scale (General Contractor’s Site Manager, personal interview, 25 October 2017).

### 4.4.5.4 Pre-refurbishment audit

A PRA was conducted by the author on the UCL Central House fit-out project. Table 4.9 presents the list of building components and materials found on site before the de-fit stage started. The PRA inventory includes the ‘item’ (building component), ‘code’ (specific for each item type – see Table 3.3), ‘quantity’ (number of items, metres or square metres), ‘quality’ (condition of the item as detailed in section 3.2.4), ‘destination’ (where it was taken), ‘waste stream’ (material stream it corresponds to) and ‘EC’ relative to the production stage of each item.

<table>
<thead>
<tr>
<th>Item</th>
<th>Code</th>
<th>Quantity</th>
<th>Quality</th>
<th>Destination</th>
<th>Waste stream</th>
<th>EC [kgCO₂eq]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cable: electrical</td>
<td>SE 03</td>
<td></td>
<td>G</td>
<td>WC</td>
<td>plastic/metal</td>
<td>N/A</td>
</tr>
<tr>
<td>[m]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cable: ethernet</td>
<td>SE 04</td>
<td></td>
<td>G</td>
<td>WC</td>
<td>metal/plastic</td>
<td>N/A</td>
</tr>
<tr>
<td>[m]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carpet tile</td>
<td>FI 02</td>
<td>926</td>
<td>G</td>
<td>WC</td>
<td>plastic/textile</td>
<td>2148</td>
</tr>
<tr>
<td>Ceiling tile</td>
<td>CL 01</td>
<td>489</td>
<td>E</td>
<td>WC</td>
<td>metal</td>
<td>3100</td>
</tr>
<tr>
<td>Ceiling tile rail</td>
<td>CL 02</td>
<td>660</td>
<td>E</td>
<td>WC</td>
<td>metal</td>
<td></td>
</tr>
<tr>
<td>[m]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ceiling insulation pad</td>
<td>IN 02</td>
<td>489</td>
<td>E</td>
<td>WC</td>
<td>insulation</td>
<td>332</td>
</tr>
<tr>
<td>Door: timber</td>
<td>OP 01</td>
<td>6</td>
<td>E</td>
<td>WC</td>
<td>wood</td>
<td>315</td>
</tr>
<tr>
<td>Door: glazed</td>
<td>OP 01</td>
<td>3</td>
<td>E</td>
<td>WC</td>
<td>glass/metal</td>
<td>256</td>
</tr>
<tr>
<td>Door: wardrobe</td>
<td>OP 01</td>
<td>8</td>
<td>E</td>
<td>RET</td>
<td>wood</td>
<td>N/A</td>
</tr>
<tr>
<td>Fire alarm</td>
<td>SE 06</td>
<td>5</td>
<td>G</td>
<td>WC</td>
<td>metal/plastic</td>
<td>30</td>
</tr>
<tr>
<td>Fire extinguisher</td>
<td>SE 07</td>
<td>2</td>
<td>E</td>
<td>RET</td>
<td>metal</td>
<td>N/A</td>
</tr>
<tr>
<td>Floor outlet: round</td>
<td>SE 08</td>
<td>40</td>
<td>G</td>
<td>WC</td>
<td>plastic</td>
<td>306</td>
</tr>
<tr>
<td>Floor outlet: square</td>
<td>SE 08</td>
<td>6</td>
<td>E</td>
<td>WC</td>
<td>plastic</td>
<td>46</td>
</tr>
<tr>
<td>Floor outlet: socket</td>
<td>SE 08</td>
<td>12</td>
<td>G</td>
<td>WC</td>
<td>metal/plastic</td>
<td>92</td>
</tr>
<tr>
<td>Furniture: chair</td>
<td>FU 04</td>
<td>33</td>
<td>E</td>
<td>STO</td>
<td>plastic/textile</td>
<td>2512</td>
</tr>
<tr>
<td>Furniture: locker</td>
<td>FU 05</td>
<td>33</td>
<td>E</td>
<td>STO</td>
<td>metal</td>
<td>758</td>
</tr>
<tr>
<td>Furniture: workstation</td>
<td>FU 06</td>
<td>33</td>
<td>E</td>
<td>STO</td>
<td>metal/wood</td>
<td>3953</td>
</tr>
</tbody>
</table>
As can be seen in the PRA inventory above, most building components and materials that were in the building prior to refurbishment were collected by the Waste Contractor. Some of the items that showed a ‘good’ or ‘excellent’ condition but were sent to the Transfer Site, including:

- 926 carpet tiles (Figure 4.32, picture a),
- 489 ceiling tiles (picture b) along with their insulation and rails,
- six timber and three glazed doors (picture c),
- 40 (round) floor outlets (picture d),
- 72 (square) light fittings (picture e),
• 14 electrical sockets (picture f).

Figure 4.32: Items in acceptable condition sent to Waste Contractor at UCL Central House fit-out: (a) carpet tiles, (b) ceiling tile, (c) glazed door, (d) round floor outlet, (e) light fitting, and (f) electrical socket.

On the other hand, some items were retained in situ, i.e. reused for the same purpose in the same location, as follows:

• all the wardrobe doors,
• all the fire extinguishers,
• 43% of HVAC ceiling cassettes (Figure 4.33, picture a) (saving 1,974 kgCO₂eq),
• 93% of the RAF tiles (picture b) (15,270 kgCO₂eq),
• all the components in the toilets (866 kgCO₂eq),
• all the windows' frames and panes (3,003 kgCO₂eq).

Figure 4.33, picture b shows some of the RAF tiles that needed to be replaced as they presented holes where floor outlets were in place.
Lastly, some items were stored by UCL Estates with the expectation to be reused in subsequent fit-out projects. Section 4.5 presents the logistics followed at UCL to store building components. Stored items at this case study comprised:

- all the office furniture such as chairs, lockers and workstations (7,223 kgCO₂eq),
- 57% of HVAC ceiling cassettes (2,632 kgCO₂eq).

For this case study, the total EC in the building products found on site prior to de-fit accounted for 54,095 kgCO₂eq. Out of this, 30,968 kgCO₂eq (57%) were saved due to items being retained or reused. The building components with the highest aggregated EC were RAF with its pedestals and stringers (which altogether accounted for 30% of the total EC), light fittings (20%) and HVAC ceiling cassettes (9%). In a similar way as in UCL Confucius Institute case study, these items resulted in relatively high EC due to the number of products found on site (e.g. 747 RAF tiles). Most RAF was retained (as mentioned earlier), and this entailed EC savings of 15,270 kgCO₂eq (28% of the total EC). Retaining light fittings would have saved further 10,935 kgCO₂eq, although this was unfeasible as new, more efficient LED lighting was to be installed during re-fit. All office furniture was stored at UCL with the expectation of being reused in other UCL fit-out projects (although this outcome may be uncertain, as later discussed in subsection 5.7.3). Salvaging and storing office furniture potentially saved 7,223 kgCO₂eq (13% of the total EC).

4.4.5.5 Material flow analysis

This subsection presents the amounts (by mass) of the waste streams generated during the fit-out process and aims to identify the paths and final destinations for each waste stream. The data presented here is based on the fit-out SWMP and discussions with key stakeholders in the fit-out waste management process.

The total waste generated during this fit-out project (considering de-fit and re-fit) was 6.38 t, with a landfill diversion rate of 98%. The RWG was 2.37 t/100 m² of GFA. Waste Report in this project did not provide a separate breakdown of waste for de-fit and re-fit. Table 4.10 shows a breakdown of the waste streams generated during the fit-out project.

As waste segregation was negligible for this case study, most waste went out as mixed waste with the exception of some mixed packaging and plasterboard. The latter was treated separately due to governmental regulations.
Table 4.10: Waste generated during de-fit and re-fit at UCL Central House fit-out (fit-out SWMP, 2017). ‘Recycled’ accounts for waste sent to Waste Contractor and ‘disposed’ accounts for waste sent to landfill.

<table>
<thead>
<tr>
<th>Item</th>
<th>Mass [t]</th>
<th>Recycled [t]</th>
<th>Disposed [t]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixed packaging</td>
<td>0.42</td>
<td>0.42</td>
<td>0.00</td>
</tr>
<tr>
<td>Mixed waste</td>
<td>4.74</td>
<td>4.61</td>
<td>0.13</td>
</tr>
<tr>
<td>Plasterboard</td>
<td>1.22</td>
<td>1.22</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>Total [t]</strong></td>
<td><strong>6.38</strong></td>
<td><strong>6.25</strong></td>
<td><strong>0.13</strong></td>
</tr>
<tr>
<td><strong>Percentage [%]</strong></td>
<td><strong>100</strong></td>
<td><strong>98</strong></td>
<td><strong>2</strong></td>
</tr>
</tbody>
</table>

Figure 4.34 presents a bar chart showing the percentages or shares (by mass) of each waste stream relative to the overall waste collection. The ROWS represented 26% of total waste arisings. For this case study, mixed waste accounted for the largest share by mass (74%) of the overall waste generated.

Figure 4.35 shows the flow of the respective waste streams across the supply chain for UCL Central House fit-out. Waste Contractor 1 was employed in this case study, so proportions of mixed waste were broken down into different waste streams according to this contractor’s waste-stream shares (see subsection 4.3.2). Mixed packaging was broken down into the respective waste streams according to Waste Contractor’s assumptions. Apart from the Waste Contractor, other downstream supply-chain stakeholders were contacted, including a staff member within a Waste Dealer (Service Supplier Coordinator, 19 June 2017) and final destinations (Quality Manager, 08 June 2017; Supplier Coordinator, 10 June 2017; Sales Manager, 15 June 2017; Sales Representative, 15 June 2017).

Out of 6.38 t of waste generated, 98% was reported as recycled, where 0.25 t was composted, 0.9 t was incinerated for energy recovery, and 0.72 t (of plasterboard) was closed-loop recycled. In total, 3.9 t (61%) of waste were exported abroad.
4.4.6 Case study: Conduit Members’ Club

4.4.6.1 Description

The Conduit project took place between August 2017 and June 2018 in Mayfair, aiming to turn formerly office spaces into a private members’ club. The 1,720 m$^2$ building is located in central London and is composed of eight stories, including six floors, a mezzanine and a basement. Figure 4.36 shows a photograph of the completed outcome of the fit-out project.

The information for this case study was provided by the Client (personal interview, 21 May 2017), the Design Team’s Sustainability Consultant (personal interview, 21 May 2017, 09 June 2017 and 01 November 2017), the Strip-out Contractor’s Site Manager (personal interview, 21 September 2017), the Strip-out Contractor’s Resource Manager (personal communication, 14 December 2017) and the reuse platform Globechain’s Owner/Director (personal interview, 01 November 2017).

The Client decided not to certify the project under a scheme such as BREEAM or SKA Rating since it was deemed that such certification schemes constrain the sustainability approach to limited alternatives and modus operandi. Therefore, the Design Team was commissioned to apply the project’s sustainability principles across the design, construction and occupancy phase. The key sustainability principles underpinning the approach of the building fit-out were: 1) LCA: taking into account the environmental impact of every building stage. 2) Occupant wellbeing: providing healthy spaces for the building occupants based on air and water quality as well as adequate lighting. 3) Efficiency: efficient use of resources, such as energy and materials, throughout the entire project life-time.
The Design Team took on the challenge of doing unusual practices such as salvaging as much as possible of the existing building’s features, including retention in situ and offsite reuse of most existing furnishings and equipment (as detailed in subsection 4.4.6.6). This challenge caused the project to be delayed. The Conduit fit-out was planned to start in July 2017 but started in September 2017. The process of planning the dynamics to salvage building components proved to be more complicated than expected (see subsection 4.4.6.6). On one hand, there was the issue of finding actors to reuse the components to be removed, while on the other hand there was the issue of logistics to get the items to their destination. Logistics concerns ranged from the careful and safe removal of components up to collection or transportation. Finally, there was also a concern about the final destination of components that followed the reuse path, as there is some uncertainty on the actual final use of these products by the new users.

4.4.6.2 Supply chain structure

The supply-chain stakeholders and structure for the Conduit Members’ Club fit-out are described and presented according to data given in personal interviews. For this purpose, different supply-chain actors were interviewed: the Client, the Design Team’s Sustainability Consultant, the Strip-out Contractor’s Resource Manager and the reuse platform Globechain’s Owner/Director.

The supply chain involved in the process was slightly different to that in the other fit-out case studies presented here. Figure 4.37 shows the supply-chain stakeholders and structure. The Client attended some of the first design meetings and, due to his busy schedule, was later represented by a Health and Safety (H&S) Representative. The Client assigned a Design Team to be in charge of the whole project design which was compiled in the Tender Package. The Design Team comprised actors from different firms respectively; namely, a Project Manager, an Architect, an M&E Consultant, a Quantity Surveyor, and a Sustainability Consultant. The Design Team appointed a General Contractor to be in charge of the works on site, and the General Contractor, in turn, appointed a Strip-out Contractor to carry out the de-fit stage. The Suppliers were selected by both the Design Team and the General
Contractor, as some building components and materials were originally specified by the Design Team and the General Contractor changed some of the specified components and added new ones. The Strip-out Contractor had their own waste-carrier license and vehicles, so they collected the de-fit waste and transported it to a Transfer Site different to the one used by the Waste Contractor. The Waste Contractor was subcontracted by the General Contractor to take care of the re-fit waste. There was another actor involved in the supply chain; the Owner/Director of a sharing platform called Globechain aided in the process of salvaging components and finding users who would reuse these components, called Re-users hereafter.

Figure 4.37: Supply-chain structure showing the decision flow and communication links, for Conduit Members’ Club fit-out (personal interviews, 2018).

The resource management in this fit-out project was different to the standard practice. During the de-fit stage, there was an attempt to salvage as many building components as possible as an alternative to waste disposal. For this reason, a Reuse third party (Globechain) was involved to find and allocate Re-users who would take the components to be salvaged. The Reuse platform’s Owner/Director was in communication with the Client, the Design Team (mainly the Sustainability Consultant), the General Contractor, the Strip-out Contractor and the Re-users, to coordinate the salvaging process. Thus, the Reuse third party (along with the General Contractor) showed five communication links, functioning as a communication node in (the upstream side of) the supply chain. As shown in subsection 4.2.2, a Reuse third party may act as a supply-chain actor with involvement in both the fit-out process and the waste-management process, which could potentially support the efficacy of communication and decision-making in the supply chain and could also increase the circularity of material flows during the fit-out process. For further detail on the procedure for salvaging of building components refer to subsection 4.4.6.6.

4.4.6.3 Fit-out procedure

The level of onsite involvement during the Conduit Members’ Club project did not allow the author to define a more detailed description of the fit-out process. The procedures shown below were obtained from interviews or personal communications with the Design Team’s
Sustainability Consultant, the General Contractor's Site and the Strip-out Contractor’s Resource Manager.

The overall de-fit process started with removal of floor finishes and then continued with removal of non-load-bearing partitions, followed by suspended ceilings and RAF, and finished with the removal of services (e.g. HVAC). The strip-out stage started on the third floor as this was the only unoccupied floor at the moment. Gradually, the offices in the building’s floors were vacated to transform the building into a construction site.

**Waste collection**

The process for waste collection was the same for both the de-fit and the re-fit process. The de-fit process was carried out by the Strip-out Contractor, which had their own waste-carrier license so they were in charge of delivering the de-fit waste to a Transfer Site. The re-fit process was performed by the General Contractor and the re-fit waste was collected by a subcontracted Waste Contractor and taken to a different Transfer Site. The procedure shown below was compiled with data obtained from the General Contractor’s Site Manager (personal interview, 24 July 2017 and 21 September 2017), and the Strip-out Contractor’s Resource Manager (personal communication, 14 December 2017).

1. Wheelie bins were placed on the site, usually with a capacity of 660 L. The bins were provided by the Strip-out Contractor and the Waste Contractor, respectively.
2. Waste was put into the bins and it was partly segregated on site. Some of the bins contained a particular type of waste, such as electrical cabling, while some other bins contained mixed waste, as seen in Figure 4.38, picture a.
3. A compactor or caged vehicle came by the building’s main entrance and the bins’ contents were loaded into the compactor, as shown in picture b. Thus, the bins’ contents were mixed inside the compactor. There was no access to data on the number of instances that waste was collected by the Strip-out Contractor (during de-fit works) and the Waste Contractor (during re-fit works).

![Figure 4.38: (a) Waste segregation during de-fit works and (b) waste collection by the Strip-out Contractor at Conduit Members’ Club fit-out.](image-url)
4.4.6.4 Pre-refurbishment audit

The PRA was not considered for this case study due to the lack of involvement with the onsite procedure prior to the fit-out project. Access to the Building Site (which then turned into a construction site) was stringent and limited.

4.4.6.5 Material flow analysis

Figure 4.39 shows the path followed by the material and components throughout the different locations across the supply chain. This fit-out project differed from the other case studies since removed material and components were not considered and treated as waste. In this instance, most furnishings and equipment were salvaged and given to Re-users. Salvaged items were taken to a yard before being collected by Re-users to be eventually used at another Building Site (as detailed in subsection 4.4.6.6). The rest of material followed the usual path, so it was taken to the corresponding MRFs before being sent to the corresponding final destinations.

![Material flow diagram](image)

Figure 4.39: Material flow throughout the corresponding locations, for Conduit Members’ club fit-out (personal interviews, 2018).

4.4.6.6 Salvaging of components

Since there was not an established methodology for salvaging building components, a procedure was improvised for this fit-out project and presented next. As detailed below, several items were salvaged following this procedure. Further discussion on how this process was developed can be found in subsection 5.7.4.

Procedure for salvaging of building components

The procedure shown below was obtained by personal observations and from interviews with the Design Team’s Sustainability Consultant (09 June 2017 and 01 November 2017), the General Contractor’s Site Manager (24 July 2017 and 21 September 2017), the Owner/Director of the Reuse platform Globechain (09 June 2017 and 01 November 2017).

According to the planned procedure, the first approach was to ask Re-users which items they wanted and how they would remove them from site. This, however, proved impractical because Re-users were generally late to their allotted appointment, dubious about which items they wanted, and they were not knowledgeable enough to remove and transport the items properly. Consequently, the Strip-out Contractor was assigned to remove the building items for Globechain (with an additional cost) and store these items at the Strip-out Contractor’s storage yard. Re-users were asked to collect the items within 48 hours; after this time period, items were to be taken to the Waste Contractor, incurring in waste disposal charges.
The following procedure is divided into three main stages: inventory, open days, and collection. The inventory compiled all the available items to be reused, the open days allowed Re-users to confirm their selections/reservations from the Globechain site, and the collection stage encompassed the logistics to get the items from the Building Site to their respective final destinations. For the collection stage, two alternatives are presented; Plan A shows the original intention whereas Plan B presents the actual procedure.

**Inventory**

1. The Architect (or interior design firm) identified which products they wanted to retain (*in situ*) or reuse (on site) for the fit-out project and marked the corresponding items on the Demolition Plans.
2. Globechain and the Sustainability Consultant walked around the site, took photographs and made an inventory list, respectively.
3. Both lists were combined in what they called the Tracker, which includes: item, location by floor, demolition phase to be removed, dimensions, quantities when available, and photograph(s).
4. Items were listed on the Globechain platform under two categories: free items and items for sale.
   a. Listings clearly stated that some items would have to be removed professionally by the Re-user, complying with H&S requirements of the site.
   b. Risk Assessments and Method Statements for the removal process were also requested. These requirements proved to be problematic in practice.

**Open days**

5. Open days were announced in the listing on the Globechain platform to allow interested parties to come to site and view/reserve the components they wanted.
6. Re-users had the opportunity to reserve items on the Globechain platform and book in for open day visits.
7. Globechain and the Sustainability Consultant walked Re-users around the site during open day visits.
8. Re-users confirmed which items they wanted, and the ability to remove items themselves.
9. The Tracker was then updated to show which items had been requested by Re-users.
10. Globechain and the Sustainability Consultant selected the Re-users using the following criteria: a) if an item was requested by more than one Re-user, whoever requested the item first would have the priority (following a first-come-first-served basis); and b) if a Re-user requested too many items (significantly more than the rest of Re-users), some of the items would be allocated to the other Re-users, regardless of the order in which the items were requested.

**Collection**

**Plan A**

11. Re-users would be in charge of removing and taking the items they reserved, complying with H&S requirements, before the demolition stage started. However, the General Contractor was appointed and highlighted risks of untrained professionals removing fixed items from the occupied building and/or construction site.
Plan B

11. The actual course of action was that the General Contractor appointed a Strip-out Contractor, who stripped out the components floor by floor using the Demolition Plans. Items on site were coloured in the Demolition Plans to indicate the corresponding pathway, as follows: green) offsite reuse, salvaged through Globechain; yellow) onsite reuse, to be kept for the same project; and red) disposal, taken by the Strip-out Contractor to a waste Transfer Site.

12. Components classified for both onsite and offsite reuse were carefully removed, palletised (as shown in Figure 4.40) and taken by the Strip-out Contractor to their yard in East London.

   a. Onsite-reuse items were to be brought back to the Building Site when needed.

   b. Offsite-reuse items had to be collected by Re-users within two days, otherwise they would be sent to landfill and waste removal charges would be incurred.

13. Globechain notified Re-users via the Globechain platform and through group emails that the corresponding items were available for collection.

14. Re-users collected the items directly from the Strip-out Contractor’s yard.

15. Globechain collected feedback data on social, environmental and economic impact of the items’ end use. This data was available for the Client to download. Re-users had previously detailed what they intend to do with the items via the Globechain platform.

Figure 4.40: Palletised carpet tiles to be stored and collected by the corresponding Re-users, at Conduit Members’ Club fit-out.

List of salvaged components at Conduit Members’ Club

Table 4.11 presents a list of the salvaged components during the de-fit process at Conduit Members’ Club. The data presented here is based on information provided by the Design Team’s Sustainability Consultant (personal interview, 09 June 2017 and 01 November 2017) and the Owner/Director of the reuse platform Globechain (personal interview, 09 June 2017 and 01 November 2017). Most of the listed items appear in plural form (e.g. doors) as there were more than one of these items, respectively. The quantities of each of the items that were salvaged were not disclosed.
The table includes the corresponding ‘item’, along with the respective ‘code’ (see Table 3.3 for code reference), ‘number of requests’ (explained below), the ‘waste stream’ they fall under according to the type of material that each item is primarily made of, and finally brief ‘details’ are given for some of the items. The list is ordered according to the number of requests made on the specific item(s). Items defined as “SOLD” were sold for a price, rather than donated. Items that were not requested by any of the potential Re-users were collected by the Waste Contractor. A total of six Re-users were considered, including three charities, two building contractors, and interestingly, one medicine student who was buying and selling building products to make a profit.

Table 4.11: List of salvaged components at Conduit Members’ Club fit-out (adapted from project’s Tracker).

<table>
<thead>
<tr>
<th>Item</th>
<th>Code</th>
<th>No. of requests</th>
<th>Waste stream</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass chandelier</td>
<td>LI 01</td>
<td>SOLD</td>
<td>glass</td>
<td>2m long, made of glass</td>
</tr>
<tr>
<td>Chandeliers</td>
<td>LI 01</td>
<td>SOLD</td>
<td>glass</td>
<td>ballroom style</td>
</tr>
<tr>
<td>Lifts</td>
<td>SE 15</td>
<td>SOLD</td>
<td>various</td>
<td></td>
</tr>
<tr>
<td>Marble wall panels</td>
<td>FI 09</td>
<td>SOLD</td>
<td>hardcore</td>
<td>backlit</td>
</tr>
<tr>
<td>CCTV cameras</td>
<td>SE 01</td>
<td>4</td>
<td>metal/plastic</td>
<td></td>
</tr>
<tr>
<td>Ceiling speakers</td>
<td>SE 01</td>
<td>4</td>
<td>plastic</td>
<td></td>
</tr>
<tr>
<td>Decorative columns</td>
<td>FI 11</td>
<td>4</td>
<td>glass (fibre)</td>
<td></td>
</tr>
<tr>
<td>Timber floor tiles</td>
<td>FI 04</td>
<td>4</td>
<td>wood</td>
<td>decorated</td>
</tr>
<tr>
<td>Ceiling tiles</td>
<td>CL 01</td>
<td>4</td>
<td>metal</td>
<td>made of perforated metal</td>
</tr>
<tr>
<td>Sockets: electrical</td>
<td>SE 12</td>
<td>3</td>
<td>metal/plastic</td>
<td></td>
</tr>
<tr>
<td>Light fittings</td>
<td>LI 01</td>
<td>3</td>
<td>metal/plastic</td>
<td></td>
</tr>
<tr>
<td>Sockets: lighting</td>
<td>SE 14</td>
<td>3</td>
<td>metal/plastic</td>
<td></td>
</tr>
<tr>
<td>Piano</td>
<td>FU 09</td>
<td>3</td>
<td>various</td>
<td></td>
</tr>
<tr>
<td>Carpet tiles</td>
<td>FI 02</td>
<td>2</td>
<td>plastic/textile</td>
<td>high-gloss finish</td>
</tr>
<tr>
<td>Entry phones</td>
<td>SE 01</td>
<td>2</td>
<td>metal/plastic</td>
<td></td>
</tr>
<tr>
<td>Fire doors</td>
<td>OP 01</td>
<td>2</td>
<td>wood</td>
<td></td>
</tr>
<tr>
<td>Flooring stone tiles</td>
<td>FI 04</td>
<td>2</td>
<td>hardcore</td>
<td></td>
</tr>
<tr>
<td>Kitchenette</td>
<td>KI 04</td>
<td>2</td>
<td>various</td>
<td></td>
</tr>
<tr>
<td>Moveable partition system</td>
<td>ST 03</td>
<td>2</td>
<td>metal/wood</td>
<td></td>
</tr>
<tr>
<td>Roller blinds</td>
<td>OP 03</td>
<td>2</td>
<td>textile</td>
<td>made of fabric</td>
</tr>
<tr>
<td>Sliding doors</td>
<td>OP 01</td>
<td>2</td>
<td>wood</td>
<td></td>
</tr>
<tr>
<td>Storage units</td>
<td>FU 03</td>
<td>2</td>
<td>wood</td>
<td>w/ flexible timber screens</td>
</tr>
<tr>
<td>Wall mirrors</td>
<td>FI 09</td>
<td>2</td>
<td>glass</td>
<td></td>
</tr>
<tr>
<td>Hardwood flooring</td>
<td>FI 04</td>
<td>2</td>
<td>wood</td>
<td>Herringbone flooring</td>
</tr>
<tr>
<td>Back lighting for marble wall</td>
<td>LI 02</td>
<td>1</td>
<td>glass/metal</td>
<td></td>
</tr>
<tr>
<td>Cabinets</td>
<td>FU 03</td>
<td>1</td>
<td>wood</td>
<td>with glazed door</td>
</tr>
<tr>
<td>Cupboard</td>
<td>KI 02</td>
<td>1</td>
<td>wood</td>
<td></td>
</tr>
<tr>
<td>Emergency exit signs</td>
<td>SI 01</td>
<td>1</td>
<td>plastic</td>
<td></td>
</tr>
<tr>
<td>Fan coil units</td>
<td>SE 09</td>
<td>1</td>
<td>metal</td>
<td></td>
</tr>
<tr>
<td>Fire extinguishers</td>
<td>SE 07</td>
<td>1</td>
<td>metal</td>
<td></td>
</tr>
<tr>
<td>Floor outlets</td>
<td>SE 08</td>
<td>1</td>
<td>plastic</td>
<td>floor box with sockets</td>
</tr>
<tr>
<td>Item</td>
<td>Code</td>
<td>No. of requests</td>
<td>Waste stream</td>
<td>Details</td>
</tr>
<tr>
<td>--------------------</td>
<td>-------</td>
<td>-----------------</td>
<td>--------------</td>
<td>----------------------------------------</td>
</tr>
<tr>
<td>Marble countertop</td>
<td>FI 11</td>
<td>1</td>
<td>hardcore</td>
<td>located in the toilet</td>
</tr>
<tr>
<td>Pin board</td>
<td>FU 01</td>
<td>1</td>
<td>wood</td>
<td></td>
</tr>
<tr>
<td>Soap dispenser</td>
<td>TO 03</td>
<td>1</td>
<td>plastic</td>
<td></td>
</tr>
<tr>
<td>Toilet bowls</td>
<td>TO 01</td>
<td>1</td>
<td>ceramic</td>
<td></td>
</tr>
<tr>
<td>Toilet sinks</td>
<td>TO 05</td>
<td>1</td>
<td>ceramic</td>
<td></td>
</tr>
<tr>
<td>Wall panels</td>
<td>FI 09</td>
<td>1</td>
<td>hardcore</td>
<td>bird’s eye maple veneer</td>
</tr>
<tr>
<td>Curtains</td>
<td>OP 04</td>
<td>0</td>
<td>textile</td>
<td>silk striped, fully lined</td>
</tr>
<tr>
<td>Partitions: glazed</td>
<td>ST 01</td>
<td>0</td>
<td>glass</td>
<td></td>
</tr>
<tr>
<td>Glass shelves</td>
<td>FU 07</td>
<td>0</td>
<td>glass</td>
<td></td>
</tr>
<tr>
<td>Joinery</td>
<td>FU 09</td>
<td>0</td>
<td>wood</td>
<td></td>
</tr>
<tr>
<td>Marble basin</td>
<td>TO 05</td>
<td>0</td>
<td>hardcore</td>
<td>located in the toilet</td>
</tr>
<tr>
<td>Stair balustrade</td>
<td>FI 06</td>
<td>0</td>
<td>metal</td>
<td></td>
</tr>
<tr>
<td>Stair handrail</td>
<td>FI 07</td>
<td>0</td>
<td>wood</td>
<td></td>
</tr>
</tbody>
</table>

Some of the salvaged building components are presented in Figure 4.41. Picture *a* presents both the 2m-long glass chandelier and the marble wall panels. The chandelier was partly broken and required minor repairs. The non-destructive removal of the marble wall panels showed itself to be a complicated and time-consuming task. Picture *b* shows the decorative columns, which (surprisingly) were some of the most requested items. Picture *c* presents both the decorated timber floor tiles and the moveable partition system.

Figure 4.41: Salvaged items at Conduit Members’ Club fit-out: (*a*) glass chandelier and marble wall panels, (*b*) decorative columns, (*c*) timber floor tiles and moveable partition system, and (*d*) toilet bowl and sink.
The timber floor tiles were made of hard wood and could be polished to make them look new, however, many of these tiles broke during removal. Picture $d$ shows an example toilet bowl and sink, which both had a relative low demand although they were in an excellent condition.

4.5 General issues of UCL fit-out

Currently, UCL has 264 buildings in its Buildings Register (UCL, 2018), which implies frequent fit-out projects across UCL Estates. Many of these fit-out projects follow (or get certified through) assessment methods such as SKA Rating (under the Office or HEI scheme) or BREEAM. However, most building materials and components that get removed during these fit-outs go to a Waste Contractor instead of being salvaged. UCL currently focuses on the reuse of items such as furniture, equipment, and laboratory equipment, and disregards other building components, although reusing can represent savings of 10%–20% of the monetary cost of buying new (UCL Waste Manager, personal interview, 15 November 2017).

The current pathways for furniture reuse at UCL are as follows (UCL Estates Strategy Manager, personal interview, 05 October 2017; UCL Waste Manager, personal interview, 15 November 2017):

- **In-house reuse:** In this pathway UCL stores removed furniture (and sometimes other items such as HVAC units) at their storage site (see UCL storage sites below) these items are kept for further reuse at subsequent UCL fit-out projects. Normally, UCL departments state what they will need (e.g. how many desks) for an upcoming fit-out project, and UCL Estates checks what they have in stock to see what second-hand items they can offer.

- **Bywaters-Reyooz:** In this pathway Bywaters (2019), a MRF, lists the items through Reyooz (2019), a sharing platform website, to find Re-users, and the latter collects the items directly from the Building Site. This pathway has only been used by UCL since around May 2017. Bywaters-Reyooz seems to be a better fit (than Warpit – see below) when they have a substantial amount of material, i.e. by bulk.

- **Warpit:** The former pathway (Bywaters-Reyooz) is being used in parallel with Warpit (2019) platform, which UCL has been using for a few years. Warpit is a peer-to-peer platform, so Re-users in this case are normally other institutions. Items can either be collected by Re-users or delivered to them by (outsourced) UCL’s porters at a cost. Warpit is a better fit for individual items than the Bywaters-Reyooz pathway.

- **JPA reuse scheme:** JPA, the main UCL furniture supplier, provides a reuse scheme for their furniture in which JPA collects their products to be reused. They disassemble and palletise them, and then re-assemble and bring them back when required. This has shown to be cost-effective for UCL.

UCL’s storage sites currently include the following (UCL Estates Strategy Manager, personal interview, 05 October 2017; UCL Waste Manager, personal interview, 15 November 2017).
Owned by UCL:

- Claire Hall: This site was originally planned to be used as laboratory and office space, but it is currently the main UCL storage site. It is located about 20 km away from the UCL Wilkins (main) Building. As this building is owned, UCL does not incur extra costs when storing items here. The costs of maintaining the building are the same regardless of its occupancy, i.e. how full of items it is.

- Gospel Oak: This site is located about 4 km away from the UCL Wilkins Building, and the building is also owned by UCL.

Managed by UCL logistics contractor (Wilson James):

- Silvertown: This site is located around 12 km from the UCL Wilkins Building. The building is not UCL owned and it is managed by its logistics contractor, Wilson James (2019), who have three warehouses at the site to store items for several other clients. UCL Estates avoids using this site to store items that might be reused soon, as there are costs incurred for storage. The charge for storage is £6 per pallet per week and all items stored here must be palletised. Transportation to and from this site is included in the contract signed with UCL, otherwise, the approximate fee Wilson James charges to other clients is between £200-£500 per load, depending on the vehicle’s size (Wilson James’s Senior Logistics Manager, personal interview, 26 October 2016).

The future plans at UCL include compiling an inventory of all furniture or similar items that are stored in UCL premises, to then properly assess what is best to do with all of these items. The possible outcomes for the stored items include, donation (e.g. to charities) or keeping some of them for UCL’s fit-out projects. According to the UCL Estates Strategy Manager, selling is generally not a good option as the action of collecting the furniture (by Re-users) compensates for the furniture price – so sharing is a mutual favour.
5 Analysis and discussion of results

5.1 Introduction to analysis and discussion of results

This chapter analyses and discusses the findings from this work, linking them with the literature review. The findings presented here were obtained from the analysis and synthesis of stakeholder interviews as well as observations during case studies of building fit-outs and of Waste Contractors. The research main question and sub-questions are addressed in this chapter while providing policy and practical recommendations that support the transition towards more circular building fit-outs.

Section 5.2 presents common characteristics found in office and HEI building fit-outs, which to some extent, can be extrapolated to non-domestic building fit-outs. Section 5.3 analyses the waste arisings from fit-out case studies. Section 5.4 discusses the transferability and uncertainty of results. Section 5.5 defines and discusses alternative end-of-life pathways for outflowing material in building fit-outs. Section 5.6 dwells on current and potential fit-out regulation and assessment mechanisms. Section 5.7 highlights particular issues encountered during the involvement with fit-out case studies. Lastly, section 5.8 proposes a basic circularity assessment method for building fit-outs along with the opportunities and barriers for circular fit-outs.

5.2 Common characteristics of non-domestic building fit-out

5.2.1 Generic fit-out supply chain

The structure and interaction of the fit-out supply chain has not been studied in the research works found in the literature review. Based on interviews and involvement with case studies, it was concluded that the generic fit-out supply chain is composed of the following actors: the Client, the Design Team, Suppliers (comprised of manufacturers and distributors), General Contractor, Strip-out Contractor (sometimes), Waste Contractor, Waste Dealers and final destinations. Actors in the background supply chain include Policy makers, Assessment methods developers, the EA and Researchers (as shown in Figure 4.2).

In all cases, the Client was an influential actor in the supply chain as they may decide on the overall sustainability level of the fit-out project. The Design Team showed the highest impact on the decision making within the project design, covering decisions such as the specification of building materials and components and the management of waste, as well as scoping sustainable measures based on the Client’s requirements or assessment methods chosen. Normally, the design team seemed more cooperative when following alternative procedures (e.g. reclaiming building components instead of sending them to a waste Transfer Site). Contractors showed less enthusiasm to implement or support alternative procedures (Jones, personal interview, 13 November 2015; author’s personal observations).

The common fit-out supply-chain showed a predominantly linear tendency both for decision and material flows. In terms of decision flow, the Client assigns the Design Team, which in turn assigns the Suppliers and the General Contractor. The latter then assigns the Strip-out Contractor and the Waste Contractor. The Waste Contractor assigns the corresponding Waste Dealers for each of the material streams (e.g. plasterboard or wood), who in turn determine the final destinations for each waste stream.
As well, there is a linear tendency for the material flow in each case study: the Suppliers produce and commercialise the building products, and the Design Team specifies the products from those available. The General and Strip-out Contractors install and remove the products, respectively. The Waste Contractor collects the waste and sorts it, to then hand over the different waste streams to the corresponding Waste Dealers which further sorts and grade the waste to finally send it to the respective final destinations.

Figure 5.1 shows the generic fit-out supply chain dividing stakeholders into four quadrants according to their level of involvement in the fit-out process and in the waste management process. Quadrant a contains the stakeholders with high involvement in the fit-out process and low involvement in the waste management process. Quadrant b would correspond to the stakeholders with high involvement in both processes. Quadrant c corresponds to stakeholders with low involvement in both processes, and quadrant d includes the stakeholders with low involvement in the fit-out process and high involvement in the waste management process.

It can be appreciated from Figure 5.1 that there are three stakeholders in quadrant d, which are actively involved in the waste management. A scheme for reducing the number of actors in this quadrant and increasing the material flow circularity is proposed below (Figure 5.4). In contrast, it can be observed that there are (generally) no stakeholders in quadrant b, which have high involvement in both the fit-out and the waste management process. An example of a supply-chain actor fulfilling these two types of involvement would be a Reuse third party.
(as shown in Figure 4.2). A fit-out case study involving a Reuse third party is presented earlier in subsection 4.4.6. Considering this quadrant division in the supply chain, there were 10 stakeholders contacted within quadrant a, three within quadrant b (which merely entailed Reuse third parties), three in quadrant c, and nine in quadrant d. In total, there were 25 stakeholders contacted within the foreground supply chain and three belonging to the background value chain.

Generally, the stakeholders at a higher level, such as the Client, the Design Team and the General Contractor, have higher influence on the specification of building materials and components and can take general decisions about waste management. However, these upper stakeholders are not tangibly involved with the waste management process and therefore are unaware of the waste paths and final destinations. On the other hand, the lower-level stakeholders, such as the Waste Contractor, the Waste Dealers and the actors in charge of the final destinations are tangibly involved in the waste management process but have negligible influence on the decision making on the fit-out process. There is thus a fragmented supply chain and a discontinuity of communication and information exchange which hinders the development of circular practices.

One interviewed Waste Contractor claimed they usually do not get involved with the design team although the Waste Contractor could help support the waste segregation process as well as encourage alternative pathways such as take-back schemes or reuse (Waste Contractor’s Environmental and Sustainability Manager, personal interview, 21 October 2016). It can be suggested that the linear tendency of the decision flows is a barrier for the circularity of the material flows or, in other words, a linear decision flow leads to a linear material flow.

Possible strategies to make the supply chain more circular are presented below. Figure 5.2 presents a circular supply chain with all the potential communication links. As can be seen, the communication and decision making in this model can flow in any direction. This model does not imply that all stakeholders should communicate with every other stakeholder, but it represents a free flow of information in which anybody is able to communicate with stakeholders at any level. A multi-directional decision flow may have the potential to improve the circularity of the material flow, as better communications among stakeholders can make the process more resource efficient and also improve the efficiency of the logistics required to move the waste around.

Figure 5.3 shows a circular material flow considering the different locations as waste moves around the supply chain. This model represents a CLSC, and it could be supported by information systems such as RFID technology (Ness et al., 2014) and material passports (BAMB, 2018; EPEA, 2018; Rose and Stegemann, 2018b). In a circular supply chain the materials and waste would ideally get back to the suppliers to be recycled into the original building products.
Figure 5.4 also presents a circular material flow. This diagram shows possible shortcuts for the material flow, to avoid waste being taken to each of the different locations (as it normally is), incurring in higher transportation costs and environmental impacts. Moving waste around London costs about £100-£150 per load (MRF’s Strategic Sustainability Manager, personal interview, 28 June 2016). Building components and materials that are removed at the Building Site can be taken directly to the Suppliers to be remanufactured or closed-loop recycled. As well, waste taken to the Transfer Site by the Waste Contractor can then be delivered to (or collected by) the Suppliers. Both dynamics act as a take-back scheme. Alternatively, waste at the Building Site or the Transfer Site can be collected by a third-party, a specialised collector who in turn would deliver the waste back to the suppliers. This supply-chain actor can be termed a Remanufacture and Closed-Loop Recycling (RCLR) third party. RCLR third parties can specialise in fit-out projects or in particular building products or waste streams. This kind of system is similar to a producer responsibility organisation (PRO) which is part of an EPR scheme, in which manufacturers are held financially and/or physically responsible for taking back their products. In the UK there are some current producer-led EPR schemes in the sector of batteries, electric and electronical equipment, and packaging, but none in the built environment (European Commission and DG Environment, 2014).

The alternatives presented here are basic concepts that could increase resource efficiency across the fit-out supply chain. However, these alternatives are not currently taking place due to the complexity of conducting business in contrasting ways (as later seen in subsection 5.7.4, where a Reuse third party was involved). Economies of scale “win”, and it is generally easier, faster and cheaper to follow established operating modes rather than looking at alternatives. Therefore, stakeholders must gradually shift to more resource-efficient practices, driven by economic incentives, which often need to be orchestrated by the local or national government (as further discussed in subsection 5.6.3), in a similar way that EPR systems have
been encouraged by government intervention (European Commission and DG Environment, 2014).

5.2.2 Generic fit-out process

Building materials and components were removed (de-fit) and installed (re-fit) in different order, depending on the case study. Thus, it was not possible to define a generic onsite de-fit and re-fit procedure from this work. Although a conclusive argument cannot be made, there were several factors that may relate to this disparity, including the General and Strip-out Contractors modus operandi, the condition of the space and the types of installed components prior to the fit-out process and the specified fit-out design (e.g. types of finishes or cladding).

However, the overall fit-out process extended from the briefing stage to the handover and occupancy and was similar for all case studies. This overall fit-out process was identified
thorough interviews and from involvement with fit-out projects. The common steps during this process are described next.

1. Briefing: The Client and/or someone representing the Client meet with some actors of the Design Team (such as the Project Manager) to assign responsibilities for the design of the project. The GPMs and environmental strategies should be scoped from this stage.

2. Design: The Design Team is in charge of designing the fit-out project, which may include aspects such as architectural, M&E specifications. The quantity surveyors will collaborate with the Design Team to stipulate the corresponding project times and budget.

3. Tendering: All the design specifications, times and budgets are compiled in the ‘Tender package’, which is made publicly available so that any Fit-out Contractor can submit a tender (i.e. offer their services). The appointed contractor will be in charge of all the onsite works.

4. Site works: This stage includes all the fit-out works carried on site by the corresponding contractor. During the de-fit (strip-out) phase, existing building components and materials are removed from site to install the new components and materials at the re-fit stage. Although the re-fit phase varies according to project and General Contractor, there is a generic process followed for the de-fit phase, which include: a) strip-out of hazardous materials (such as asbestos), b) soft-strip implies the strip-out of any building component and material apart from structural, and c) building works includes anything structural such as concrete, hardcore and timber.

5. Handover and occupancy: At the handover stage the building or fit-out project is handed back to the Client; ideally an O&M manual is developed by the General Contractor to guide users as they occupy the new building or space.

5.2.3 Key fit-out materials and components

Building materials comprise any material that constitutes a building component or that is adhered to a building component or element, while building components include any element installed in a building that provides a functional or aesthetic utility, usually made up of more than one material. Material and components considered below are those that were found during case studies and/or systematically mentioned during interviews with stakeholders, such as Fit-out Contractors or Waste Contractors.

Table 5.1 and Table 5.2 include the common building materials and components, respectively, that are installed and removed during fit-out projects, along with their corresponding EWC codes and the waste streams that they usually fall into. Most waste streams in building fit-outs are classified as non-hazardous waste, while hardcore (including ceramics) is inert waste, gypsum (including plasterboard) is categorised as SNRHW, and paint, adhesives and fluorescent lights (due to their mercury content) are classified as hazardous (EA, 2010).
Table 5.1: Typical materials found in building fit-outs.

<table>
<thead>
<tr>
<th>MATERIALS</th>
<th>EWC code</th>
<th>Waste stream</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ceramics</td>
<td>17 01 03</td>
<td>hardcore</td>
</tr>
<tr>
<td>Glass</td>
<td>17 02 02</td>
<td>glass</td>
</tr>
<tr>
<td>Gypsum (including plasterboard)</td>
<td>17 08 02</td>
<td>gypsum</td>
</tr>
<tr>
<td>Hardcore</td>
<td>17 01 07</td>
<td>hardcore</td>
</tr>
<tr>
<td>Insulation</td>
<td>17 06 04</td>
<td>varies</td>
</tr>
<tr>
<td>Metals -Ferrous</td>
<td>17 04 05</td>
<td>metals</td>
</tr>
<tr>
<td>Metals -Non-ferrous</td>
<td>17 04 01*</td>
<td>metals</td>
</tr>
<tr>
<td>Mixed waste</td>
<td>17 09 04</td>
<td>mixed waste</td>
</tr>
<tr>
<td>Paint, adhesive, etc.</td>
<td>20 01 27</td>
<td>hazardous</td>
</tr>
<tr>
<td>Paper &amp; Cardboard</td>
<td>20 01 01</td>
<td>paper</td>
</tr>
<tr>
<td>Plastics (including packaging)</td>
<td>17 02 03</td>
<td>plastics</td>
</tr>
<tr>
<td>Textiles</td>
<td>N/A</td>
<td>textiles ⎯ mixed waste</td>
</tr>
<tr>
<td>Wood (including fibreboard)</td>
<td>17 02 01</td>
<td>wood</td>
</tr>
</tbody>
</table>

Symbols: ⎯ means OR

* Non-ferrous metals also include EWC codes 17 04 02, 17 04 03, 17 04 04 and 17 04 06.

Table 5.2: Typical components found in building fit-outs.

<table>
<thead>
<tr>
<th>COMPONENTS</th>
<th>EWC code</th>
<th>Waste stream</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carpet/carpet tiles</td>
<td>N/A</td>
<td>textiles ⎯ mixed waste</td>
</tr>
<tr>
<td>Door</td>
<td>N/A</td>
<td>glass ⎯ metals ⎯ plastics ⎯ wood</td>
</tr>
<tr>
<td>Ductwork</td>
<td>N/A</td>
<td>metals</td>
</tr>
<tr>
<td>Electrical socket</td>
<td>N/A</td>
<td>metals &amp; plastics</td>
</tr>
<tr>
<td>Fluorescent light</td>
<td>20 01 21</td>
<td>glass &amp; metals &amp; hazardous (mercury)</td>
</tr>
<tr>
<td>Light fitting</td>
<td>N/A</td>
<td>metals &amp; plastics</td>
</tr>
<tr>
<td>Office furniture</td>
<td>N/A</td>
<td>varies</td>
</tr>
<tr>
<td>Resilient flooring</td>
<td>N/A</td>
<td>varies</td>
</tr>
<tr>
<td>RAF</td>
<td>N/A</td>
<td>metal &amp; wood ⎯ hardcore</td>
</tr>
<tr>
<td>Suspended ceiling tiles</td>
<td>N/A</td>
<td>Mixed waste</td>
</tr>
<tr>
<td>WEEE</td>
<td>20 01 36</td>
<td>WEEE</td>
</tr>
</tbody>
</table>

Symbols: & means AND; ⎯ means OR

As can be observed, there are generally no EWC codes for building components, except for the case of fluorescent lights and WEEE. This limitation hinders the capability to record and measure the flow of components in the built environment. Building components that get removed during fit-out projects are normally recorded either as mixed waste or fall under a specific waste stream. This tendency narrows the detail of information in fit-out SWMPs and Waste Contractors’ reports. For instance, the mass of metals or wood may be reported during a fit-out project, however, it is unfeasible to know the types of building components contained in each waste stream, entailing a loss of information. Waste classification and coding should be fully compatible with materials and components found in the building industry since C&D waste accounts for the largest share of the total waste generation (BRE, 2008).
**Embodied carbon in building products**

Each building product entails EC released during its production stage, including raw material extraction and processing, transport to manufacturing site and manufacture, as listed in Table 0.5 in Appendix E.

Large items such as the water boiler and the HVAC ceiling cassette represent the highest EC per product. However, the aggregation of smaller items such as carpet tiles, ceiling tiles, light fittings or fluorescent tubes account for higher overall shares of EC, due to large amounts of pieces used (e.g. 1,360 carpet tiles were removed during UCL Confucius fit-out).

Retaining or reusing such building products would save significant EC; however, there are technical barriers that would make reusing impractical. For instance, it was required to replace fluorescent light fittings with new, more efficient LED lighting. Carpet and ceiling tiles could not be retained *in situ* due to visual deterioration. In addition, ceiling tiles were easily damaged during removal. Small items such as these should be designed for closed-loop recycling to allow recurrent replacement while reducing the environmental burden.

Out of all the building products presented in the PRA inventories, RAF (including tiles, pedestals and stringers) showed the highest EC. It is thus advisable to retain these for as long as possible. In the future, RAF should be designed with long lifespan and with availability of spare parts for proper maintenance or repair. The same criteria apply to large items such as the water boiler, the HVAC ceiling cassette and office furniture.

### 5.3 Waste generation based on case studies

#### 5.3.1 Introduction to this section

The majority of removed building materials and components were considered and treated as waste, regardless of their quality or condition. This section discusses the RWG and main types of waste streams generated during fit-out case studies, as well as the ROWS and the pathways followed by these waste streams.

#### 5.3.2 Rate of waste generation

As stated in subsection 2.5.1, the KPI of tonnes of waste per 100 m² of GFA was used as an indicator for the RWG. Figure 5.5 presents the RWG for three of the analysed fit-out case studies along with those reported in the literature review. The pilot case study (Bank offices fit-out) was not considered in this analysis as it is not representative of a full fit-out process. Accordingly, three office and three HEI buildings are considered. The BBP (2015) office case study took place in Sydney, Australia, while the rest of the considered fit-out cases took place in the UK. For the cases reported by the CRW (2009) the RWG is averaged from two HEI buildings and four office buildings, respectively.
Both UCL Confucius Institute and UCL Central House fit-outs presented a RWG which is lower than the reported average for HEI buildings (CRW, 2009). The UKGBC offices fit-out also showed a RWG below the average for office buildings (CRW, 2009). In the case of UCL Central House, the RWG was low (relative to the respective average) partly due to the fact that several building components were either retained (in situ) or stored at UCL’s storage site. Namely, all the items in the toilet and most of the RAF were retained. All the furniture was stored, while the HVAC ceiling cassettes were either retained or stored. The RAF, the furniture and the HVAC units constituted a significant mass which was salvaged and did not account towards the RWG.

Collating the RWGs obtained from fit-out case studies with those from the literature, the average fit-out RWG for HEI buildings is 16.08 t/100 m$^2$ of GFA, and the average for office buildings is 6.25 t/100 m$^2$. Thus, HEI buildings fit-outs averaged a RWG which is 257% higher than office buildings. The discrepancy of RWGs between types of space (i.e. office or HEI) might be subject to the sort of building components and/or the density of installed components per floor area. However, the rationale behind this discrepancy is not reported in the literature and thus remains an issue for further study. In line with this, BREEAM (2016) provides a RWG threshold of 11.1 t/100 m$^2$ for fit-out projects, regardless of the type of space, although a different criteria should be followed depending on the space type.

In terms of RWG between the re-fit and de-fit stage, there were differing findings. The UKGBC offices fit-out presented a RWG 284% higher for the de-fit stage, which is aligned to the author’s expectations, since most building materials and components get removed at this stage. Conversely, UCL Confucius Institute fit-out showed a RWG 189% higher for the re-fit stage. The latter relates to the fact that the space was unused and almost empty before the fit-out process began, so the mass of removed material and components was relatively low. Another factor that may have contributed to a higher re-fit RWG is that some components were removed and replaced at the re-fit stage, such as floorboards and the stair...
handrail. Likewise, two internal partitions were modified (by creating an opening in them) at the re-fit stage, generating a considerable mass of waste.

5.3.3 Main waste streams generated

Figure 5.6 shows the shares (by mass) of each waste stream generated relative to the total waste generation at each fit-out project, for the UKGBC offices, UCL Confucius Institute and UCL Central House fit-outs. Data was provided by the Waste Contractor for each case study in the form of a separate Waste Report.

![Figure 5.6: Share (by mass) of each waste stream relative to the total waste generation at each fit-out project, for three of the fit-out case studies (UKGBC offices SWMP, 2016; UCL Confucius Institute SWMP, 2017; UCL Central House SWMP, 2017).](image)

There were differing findings among the fit-out case studies analysed here. For the UKGBC offices, plasterboard was the main waste stream, followed mixed waste and wood. At UCL Confucius Institute, hardcore accounted for the largest share, followed by wood and mixed waste. At UCL Central House, mixed waste was the predominant share, followed by plasterboard and mixed packaging, which were the only waste streams generated at this case study. Mixed waste and plasterboard waste were present at these three fit-out case studies, wood waste was generated at two of the case studies, while the rest of waste streams were present at only one of the case studies.

The average share was calculated based on the shares per waste stream for each case study, relative to the total waste (by mass) generated at the respective case study. For example, plasterboard accounted for 44% of the total waste generated at the UKGBC offices, 7% at UCL Confucius Institute and 19% at UCL Central House, so the average share of plasterboard waste generation is 23.4%, as stated below. Mixed waste accounted for the largest average share (41.9%), followed by plasterboard (23.4%), wood (11.2%), hardcore (8.9%), textiles (2.5%), metals (2.4%), office furniture (2.4%), mixed packaging (2.2%), insulation (1.7%), plastics (1.5%), glass (1.3%) and asbestos with (0.5%).
Figure 5.7 shows a comparative bar chart of the waste collected by both Waste Contractors. The chart shows the respective shares (by mass) for each Waste Contractor for the corresponding period. The difference in the proportions of waste streams that each contractor collected may be related to the fact that Waste Contractor 1 handles general C&D waste, while Waste Contractor 2 specialises in fit-out and refurbishment projects. Considering both Waste Contractors, mixed waste accounted for the largest average share (50.5%), followed by plasterboard (18.4%), wood (12%), metals (8.2%), hardcore (3.6%), glass (3%), RAF (2%), paper & cardboard (1.6%), insulation, plastic, textiles (0.2%, respectively), WEEE and fluorescent lamps (0.1%, respectively).

Figure 5.8 illustrates the average share (by mass) for the waste generated during three of the fit-out case studies (the UKGBC offices, UCL Confucius Institute and UCL Central House) as well as the average share for the waste collected by the two Waste Contractors, respectively. To estimate which were the overall major waste streams generated based on all the case studies, the results (shown in Figure 5.8) for both the fit-out and Waste Contractor case studies were averaged. Accordingly, the main waste stream generated was mixed waste (with an overall average share of 46.2%), followed by plasterboard (20.9%), wood (11.6%), hardcore (6.3%) and metals (5.3%).

These results are aligned to some extent with the findings reported by the Better Building Partnership (2015) in Australia, where the main shares of wastes generated during a fit-out case study comprised mixed waste, metals, hardcore and plasterboard, in that order. Likewise, the Institute for Sustainable Futures (2014) in Australia, based on interviews, reported plasterboard, mixed waste and wood (furniture and MDF) were the main waste streams generated.

![Figure 5.7: Share (by mass) of each waste stream relative to the overall waste collection, for Waste Contractor 1 (yearly for 2016 – C&D waste) and Waste Contractor 2 (first quarter of 2017 – mainly fit-out waste) (Waste Report from Waste Contractor 1 and 2, respectively, 2017).](image-url)
It is thus pertinent to allocate efforts for higher value recovery from plasterboard and wood. Higher ratios of onsite waste segregation would probably allow higher rates of high-quality recycling of plasterboard and wood, due to less risk of cross-contamination in these waste streams and diminished material losses during the segregation process at Transfer Sites and/or MRFs. Current regulations (UK Government, 2010) for waste management of gypsum-based products encouraged higher rates (60%) of closed-loop recycling for plasterboard (than for any other material) but this percentage can still be improved. In the case of waste wood, the use of a non-toxic, biodegradable binding materials would increase the value of fibreboard and particleboard, by allowing a more valuable recycling output.

5.3.4 Ratio of waste segregation
The ROWS is the percentage of segregated waste relative to the total waste generation. Segregated waste includes every waste stream except for mixed waste. UCL Confucius Institute showed the highest ROWS, followed by the Bank offices, UKGBC offices and UCL Central House, where the ROWS was relatively low. Based on these four case studies, the average ROWS was 62.5%.

UCL Central House and UCL Confucius Institute fit-outs used the same General Contractor and Waste Contractor, however the ROWS at Confucius fit-out was over three times higher than that at UCL Central House. The colour-coding for the 360L wheelie bins at UCL Confucius Institute seemed to have encouraged waste segregation at the re-fit stage. The General Contractor’s staff were not required to segregate waste, but the Waste Contractor provided colour-coded wheelie bins (as presented in subsection 4.4.4.3) and this apparently increased the ROWS. The wheelie bins were set as follows: blue for metals, black for mixed waste, brown for cardboard and paper, green for wood, red for plastic and yellow...
or white for plasterboard. A similar colour-coding as the one used in this case study can be defined as a standard to encourage and facilitate waste segregation. Cages helped keep apart the segregated waste inside the Waste Contractor’s vehicles.

### 5.3.5 Waste stream pathways and final destinations

A high rate of landfill diversion was reported in the analysed fit-out case studies. Namely, 99% of waste was diverted from landfill in the case of the UKGBC offices fit-out, 91% in the UCL Confucius Institute fit-out and 98% in the UCL Central House fit-out. These rates of landfill diversion were higher than the rate reported by the Better Building Partnership (2015) in Australia, where 60% of the waste was diverted from landfill.

The high rates of landfill diversion encountered during this study are likely to be related to the Landfill Tax implemented in the UK in 1996 (Seely, 2009). However, reported recovery rates by Waste Contractors were based on whether waste was sent to recycling companies, rather than whether it was in fact recovered or recycled. The average recovery rate in the UK for C&D waste is around 90% (TCS, 2013; DEFRA, 2020; Eurostat, 2019a). Moreover, WRAP (2010) reports that 23% of sorted C&D waste ends up in landfill, and as much as 46% of mixed C&D is landfilled. Given these figures, it results implausible to achieve the landfill-diversion rates reported by Waste Contractors.

During this study, it became evident that material losses from transportation, sorting and recycling processes are not properly accounted for across the supply chain, although these processes can be highly wasteful (Rose and Stegemann, 2018a). Apart from that, an apparent lack of accurate and comprehensive information in the waste holders’ records suggested some level of ambiguity about the reported recovery or landfill-diversion rates for the analysed case studies, as further discussed in subsection 5.6.2.

Figure 5.9 shows how material flowed throughout the corresponding locations for all fit-out case studies except Conduit Members’ Club, specifying the location in the supply chain where material losses may have been unreported or unaccounted for. Negligible material losses were observed by the author at the Building site during fit-out processes, and the involved Waste Contractor reported no material losses in their Transfer site (although these may have been underreported). Down the supply chain, unreported material losses likely took place at MRFs and final destinations, where waste was further sorted and processed. This “material loss propagation” may be unaccounted for in the landfill-diversion rates reported by the Waste Contractor.

![Figure 5.9: Material flow throughout the corresponding locations for four of the fit-out case studies, specifying the location in the supply chain where material losses may have been unreported or unaccounted for.](image-url)
The same Waste Contractor was employed at the four fit-out case studies where MFAs were carried out, partly due to this contractor’s market dominance in the area of study, and also because the case studies were selected through chain-referral sampling. Mixed waste was broken down into specific waste streams according to this contractor’s bulk data. According to the MFAs, waste streams generally diversified into multiple final destinations that require a lower grade of material quality, with the exception of a share of plasterboard, which was closed-loop recycled into new plasterboard. Final destinations included downcycling, composting and energy recovery. Plasterboard was the only waste stream that showed some percentage of closed-loop recycling, driven by UK regulations which stipulate a special treatment for gypsum-based products since 2009 (UK Government, 2010) and derived from European Union regulations implemented in 2005 (Eurogypsum, 2015).

Metals were exported to Spain or Turkey, plastics ended up in China, while wood was sent to Belgium. This led to an export share (relative to the total waste generated) of 35% in the case of the UKGBC offices fit-out, 42% for UCL Confucius Institute fit-out and 61% for UCL Central House fit-out. Given this tendency, it is concluded that the UK should invest more in waste-treatment infrastructure that can support high-quality recycling or energy recovery from waste, as further discussed in subsection 2.4.7.

5.4 Transferability and uncertainty of results

The sample size in this study is too small to draw robust statistical inferences. Results on waste generation for fit-out case studies cannot be analysed statistically as there are too few values per variable, and in some instances, there is only one value per variable. For example, only one case study reported waste hardcore, and this is pervasive for textiles, office furniture, metals, mixed packaging, insulation, plastics, glass and asbestos. A larger sample size may allow to conduct a statistical analysis to define the uncertainty in the data.

For the case of RGW, there are at least three values per variable, including the values obtained from literature. The standard deviation (SD) in the RWG of HEI fit-outs is 16.03 t/100 m$^2$, and for the office fit-outs the SD is 3.83 t/100 m$^2$. The equation below (Verma, 2012) was used to quantify the uncertainty for RWG based on the SD:

$$\text{uncertainty} = \frac{SD}{\sqrt{n}} T(n - 1),$$

where $n$ is the sample size, and $T$ is the t student value for that given sample size and for a confidence interval of 95%. The uncertainty for RWG in HEI fit-outs was calculated as 39.79 t/100 m$^2$ and for office fit-outs this uncertainty is 9.50 t/100 m$^2$. Given this high uncertainty, RWG results cannot provide statistical generalisation.

Therefore, quantitative results on waste generation in this work are not reproducible. Conducting further studies using the same or a similar methodology would allow more statistically robust results.

On the other hand, qualitative data in this work was obtained from interviews, and the uncertainties posed in expert opinion cannot be evaluated by statistical means (IPCC, 2001). The qualitative contribution of this work provides thick data, which can be combined with
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5.5 Alternative end-of-life pathways

5.5.1 Summary of alternative end-of-life pathways

During this study, it has been shown that waste management procedures in building fit-outs tend to be standardised and the path followed by waste was similar across different fit-out projects. The most common path followed by removed building materials and components was to be collected by a Waste Contractor and taken to a Transfer Site, to then be sent to a MRF before reaching the final destinations (e.g. recycling). Normally, waste paths and final destinations are determined by market (prices) or convenience (in terms of time and space) rather than environmental criteria. However, there are different paths for end-of-life building components and materials that entail savings in energy and carbon emissions. Figure 5.10 presents some of the alternative paths that a building component can follow. The diagram presents the case of an electrical socket, although the concept is applicable for most building products. Alternative pathways for removed building materials and components include: retain (*in situ*), onsite and offsite reuse, remanufacture, and closed-loop recycling. On the other hand, conventional end-of-life treatment generally entails downcycling.

![Diagram of alternative pathways for an end-of-life electrical socket](image)

Each of these alternative pathways relate to different criteria and approaches. Figure 5.11 shows relevant factors that underpin the success of different pathways, namely, retain (*in situ*), reuse, remanufacture, recycle, and downcycle, ordered in a descending manner accord-
ing to their preferability in terms of resource consumption and minimisation of environmental impacts. In this diagram, there is a differentiation between recycling and downcycling, where ‘recycle’ refers to closed-loop recycling and ‘downcycle’ refers to any other treatment which somehow decreases the material quality of the original building material or component. Each of the different pathways are indicated (on the left) next to the corresponding oval (on the right). These ovals contain the factors that relate to each pathway. Factors that relate to more than one pathway are presented at the corresponding intersection. The next two subsections provide more detail into the pathways of reuse, remanufacture, and closed-loop recycling.

Figure 5.11: Relevant factors that relate to the different end-of-life pathways (author generated).

5.5.2 Reuse
It is evident that reusing building components and materials leads to savings in energy, carbon emissions, natural resources, and avoids significant waste, while potentially reducing
monetary costs (of buying new products). Although furniture reuse is a well-established prac-
tice in the UK (WRAP, 2011), the overall reuse rate of building products is currently very low.

The fit-out case studies in this work have shown that fit-out processes produce recurrent and
significant amounts of waste since these practices entail more frequent rates of replacement
of building components than other building activities. A large amount of waste generated
during fit-outs comprises items in acceptable condition that could be reused. Nonetheless,
the vast majority of these reusable items across most fit-out projects are treated as waste and
are downcycled, incinerated or landfilled.

One important reason for a low reuse rate in fit-out practices, is the desire of the Client and
the architect to incorporate new building components from the design stage. This mainly
happens for two reasons: on one hand, the mindset that new is better, so it is deemed that
new building components will lead to a more aesthetically pleasing space; and on the other
hand, the current take-make-dispose model formed practices in which it is easier to throw
away everything and install everything new from scratch. This is an underlying reason why
reusing components normally entails more time and space for the stakeholders; but this can
change.

Another reason why building components are not often reused is because products are not
initially designed to be removed, reused or properly recycled. This fact relates to issues such
as lack of size standardisation, short lifespans, unavailability of spare parts, and difficult or
impossible removal or separation.

At UCL Confucius Institute fit-out, it was observed that the lack of standardisation in build-
ing components complicated the reuse rate at a large scale. For instance, Table 4.7 shows
the disparity among the doors found before refurbishment. As can be seen, there were 22
doors in the building with different dimensions, where only two of them had equal dimen-
sions. As well is the case for items such as the counters or cupboards which are tailored for a
particular space.

At Conduit Members'Club fit-out, RAF tiles were sent to a Waste Contractor as the pedes-
tals were not made anymore. The lack of availability or accessibility of spare parts for prod-
ucts created a premature functional obsolescence. The General Contractor’s Site Manager
(personal interview, 21 September 2017) claimed that RAF tiles usually have a life expectancy
of 12 to 15 years and the tiles at this project had about half of their lifespan left. The difficulty
of non-destructive removal made it unfeasible to reuse the timber floor tiles found on site,
although there already were potential Re-users interested in these items. The metal ceiling
tiles were salvaged by Re-users at this case study, however, it was suspected (by the author)
that these particular building components were sought after because of their material value
rather than for their functional value. Accordingly, the value of the material content of a
component could be greater than the value of the component, leading to less reuse and more
recycling.

Therefore, to make a product more reusable, it must:

- have a lifespan that allows several use cycles,
be standardised in size so it can be fitted in other construction projects,
providing connections that make it easy to be removed and re-installed.

Likewise (to encourage higher reuse rates) manufacturers should:

- stipulate the average lifespan of their products,
- state whether their products have built-in obsolescence,
- declare if the spare parts can be purchased separately and when these will be discontinued.

Lastly, to swiftly find Re-users who would reuse the product, it is necessary to make use of sharing platforms, or Strip-out Contractors with a supply chain that can make this happen. A product can be completely reusable but will be disposed of if nobody is there to reuse it.

### 5.5.3 Relative reuse cost

The Relative Reuse Cost can be used as an indicator to evaluate the monetary cost or “environmental convenience” of reusing a specific building component instead of replacing this component with a new one. In other words, the Relative Reuse Cost estimates the value or cost-benefit of reusing a certain building component, and it is given by the following equation

\[
\text{Relative Reuse Cost} = \frac{\text{Reuse Cost}}{\text{Residual Lifespan}} \div \text{Replacement Cost}
\]

Where the Reuse Cost is the monetary or environmental cost of reusing a certain item (see below). The Residual Lifespan is the percentage of the item’s remaining lifespan, where a value of 1 indicates a full (new product) lifespan and a value of 0.5 indicates only half of the corresponding lifespan is remaining. This would rely on the average lifespan specified for the corresponding product or assumed from a standard product. The Replacement Cost is the monetary or environmental cost of replacing the item (see below).

In this way, a resulting Relative Reuse Cost of 2 indicates that reusing a given product (under a specific circumstance) would cost twice as much as replacing the product; a value of 1 means the cost of reusing is the same as the cost of replacing, and a value of 0.5 would mean that reusing costs half of the replacement cost. So, the lower the Relative Reuse Cost the more beneficial the choice of reusing.

From a monetary cost [£] approach, the Reuse Cost is given by summing the following costs associated with the item’s reuse:

- non-destructive removal (per item);
- transport (given by mass [t] or volume [m$^3$] per km and normalised to item);
- storage (given by volume or cross-sectional area [m$^3$ or m$^2$] and normalised to item);
- maintenance/testing (per item);
- delivery and installation (per item).

The Replacement Cost is given by summing the following costs associated with the item’s replacement:

- standard removal (per item);
• Waste Contractor’s fee (normalised);
• price of new product, including delivery and installation (per item).

From an environmental cost (carbon emissions) approach, the *Reuse Cost* is given by summing the carbon emissions associated with the following aspects of the item’s reuse:

• transport from Building Site to storage (normalised);
• transport from storage to Building Site (normalised);
• maintenance and installation.

The *Replacement Cost* is given by summing carbon emissions associated with the following aspects of the item’s replacement:

• transport from manufacturer/supplier to Building Site (normalised);
• the item’s production process (per item);
• installation.

The *Relative Reuse Cost* could be useful for businesses or institutions to calculate how far a removed item can be transported or for how long it can be stored, so the reuse option is cost-effective. The implementation of this indicator was discussed with the UCL Waste Manager (personal interview, 15 November 2017); they showed interest and tried to collate the corresponding information to allow for some calculation tests. However, in practice it was unviable for UCL staff to put together such information, due to time constraints. A systemic approach at institution level to record and/or estimate the necessary information would allow to calculate in which cases reusing is a more convenient option than replacing. To support the availability of information on products’ average lifespan, regulations should drive manufacturers to state the average lifespan of their products, as later discussed in subsection 5.8.3.

### 5.5.4 Remanufacture and closed-loop recycling

Apart from reuse, remanufacture and close-loop recycling are other favourable options to treat end-of-life building products. When remanufactured, products are taken back to the manufacturing process to be transformed back into the original product. Closed-loop recycling comprises any recycling practice in which the material and/or functional value is maintained. Accordingly, remanufacturing is a similar approach to closed-loop recycling.

The main factors that allow for remanufacturing and closed-loop recycling are separability, purity and logistics. Separability refers to the ease to separate the different parts of layers of a product. It is crucial to be able to separate the product, as each of its parts or layers must follow a different path in the recycling process. Purity is related to the product’s chemical composition, and it is recommendable that products have as few different inputs as possible or should provide a means to effectively separate these inputs. A product which incorporates indivisible mixtures of technical and/or biological materials can hardly be recovered and end of life.

Logistics is another important factor underpinning the viability of remanufacturing and closed-loop recycling. End-of-life products must find an efficient way to reach back to the economy, being for instance, remanufactured or close-loop recycled. One option for this to
happen, is the so-called take-back schemes in which manufacturers can collect their products at end of life from the Building Site and transport them back to the manufacturing process. Although take-back schemes are becoming fashionable, relatively little reverse logistics takes place since the current take-back schemes are constraining for the contractors. A General Contractor’s Environmental and Sustainability Manager (personal interview, 27 September 2016) mentioned that they hardly use these take-back schemes due to the constraints that are imposed, for example: minimum quantities or grades, just a few lines of products are included and waiting time for collection.

Policies or measures to encourage the widespread use of take-back schemes may greatly benefit producers, consumers and the environment:

- EPR could be enforced on producers to encourage further availability and accessibility of take-back schemes.
- RCLR third parties or producer responsibility organisations (PROs) would aid producers by making reverse logistics more efficient and cost-effective.
- Tax breaks on remanufacturing would also encourage producers to pursue more effective take-back schemes (as mentioned in subsection 5.6.3) and thus increase the rates of remanufacturing and closed-loop recycling. The ratio of the original material preserved in remanufactured goods can be a criterion to reflect on the circularity of a remanufacturing process.

5.6 Regulation in building fit-out
5.6.1 Fit-out assessment methods

Regulation or assessment mechanisms provide useful sustainability guidelines for building fit-outs. The development and implementation of these guidelines are crucial for a favourable development in the construction industry, both under a top-down or a bottom-up approach. Assessment and certification methods can certainly support more circular practices in building fit-outs by preserving the value of removed materials and components and procuring building products with high circularity potential.

Analysis methodologies such as MFA and LCA are useful tools for assessing the sustainability of building fit-outs. However, these tools overlook social and economic aspects (such as social impact or cost-benefit) and do not fully evaluate the circularity in fit-out projects from a life-cycle perspective. It is difficult or unfeasible to know whether a building material or component will be retained, reused or remanufactured, as this only takes place in the future, so end-of-life pathways become uncertain (Ding, 2014).

Certification methods such as SKA Rating (RICS, 2016), BREEAM (BRE, 2016) or LEED (USGBC, 2016) are lightly based on LCA. Although these methods provide easy-to-use benchmarking, they still show a low (but rising) uptake at the moment (ECORYS, 2014) and also entail an additional expense for the user. During this study, it was perceived that budget was usually the priority for supply-chain stakeholders, followed by function, then aesthetics and finally life-cycle sustainability. Therefore, financial incentives would drive higher uptake of certification methods. It would not be advisable to make these assessment schemes man-
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Mandatory as this would encourage monopolising (Waste Contractor’s Environmental and Sustainability Manager, personal interview, 21 October 2016). Currently available assessment methods are owned and managed by private companies, so making a particular assessment scheme compulsory would entail an advantage for a specific company over its competitors. Thus, only government-led or free assessment methods should be made mandatory.

Overall, SKA Rating was perceived to be easier to follow than other assessment methods (Waste Contractor’s Environmental and Sustainability Manager, personal interview, 21 October 2016). However, being a UK-based system, it may be challenging to properly assess and compare fit-out projects in other countries, since the environmental, technical and regulatory criteria might be different. Comparability is a common issue for any assessment or certification method, so it is thus pertinent to develop standard indicators that are transferable regardless of the method used.

KPIs are crucial for assessing and comparing building fit-outs. Examples of KPIs are the ones designed for measuring waste generation during fit-out or refurbishment projects, although there is still no convention or agreement on the best KPI for this purpose. Common KPIs for measuring waste generation include tonnes of waste per 100 m$^2$ of GFA, tonnes of waste per £100k of project value, m$^3$ of waste per 100 m$^2$ of GFA, and m$^3$ of waste per £100k of project value (CRW, 2009). GFA represents a more objective normalising parameter than the monetary value of a project, since one fit-out project might have more expensive building components than others (UCL Sustainability Manager, personal interview, 23 October 2017).

Currently, the most widely used KPI for measuring RWGs is tonnes of waste per 100 m$^2$ of GFA, which is intended to reflect the sustainability and efficiency of the resource management during the fit-out process. This indicator depends on the design and development of the fit-out project, but it also depends on the amount of materials and components installed in the building prior to fit-out, which is a pre-existing condition. Therefore, the amount of pre-installed items on site affects the RWG but it is not intrinsic to the fit-out process and does not necessarily reflect on the quality of the resource management during the process, which makes this indicator biased. Also, the environmental burden of the diversity of building products is not necessarily determined by mass. For example, insulation materials can represent a higher environmental impact than metals or ceramics, despite their low density. Unlike the Landfill Tax which is lower for inert waste such as ceramics (UK Government, 2019a), certification schemes like BREEAM (BRE, 2016) are based on RWGs which do not differ between the environmental impact of each type of waste.

PRAs are essential to better assess and manage a fit-out project. It is pertinent to make an inventory of all installed building products and the condition they are in to elucidate potential alternative end-of-life pathways, such as retaining or reuse. Accordingly, a PRA inventory can also support the assessment of circularity of the fit-out process, as suggested later in subsection 5.8.3, in which a modified PRA inventory is proposed to assess the circularity of each building item found on site, based on their respective end-of-life pathways. It is worth noting that if there were a proper inventory of what was in the building site in the first place (e.g. through asset tracking), there would not be a need to conduct a PRA inventory.
5.6.2 Availability of waste management data

From involvement with fit-out case studies, it was perceived that there is a discontinuity of communication and information among fit-out supply-chain actors, even within the same fit-out project or within the same institution. An interesting finding was that the availability and comprehensiveness of information decreased as material became waste across the supply chain. This means that the closer to where waste handling occurred, the more reluctant actors were to share information. This might, however, also be related to the fact that the interviews were conducted through chain-referral sampling, generally starting at the upstream side of the supply chain.

According to DEFRA (2014), all waste holders must record waste-stream inputs and outputs, stating where the outputs are sent onwards for further processing and/or to be used or recycled. However, interviewed stakeholders did not seem to have this information in order and the aggregate of this information is not openly available and it is not effectively being considered for developing policies that shift waste management towards resource conservation, instead of being based on landfill-diversion targets.

Out of the contacted waste holders (i.e. Waste Contractors, Waste Dealers (MRFs) and final destinations), only one of them was able or willing to provide detailed information about the recycling output of the corresponding waste streams. Namely, a London-based glass collector (MRF) stated that out of the totality of glass they receive annually, 88% is re-melted into new glass products such as bottles, jars, and glass wool (loft insulation) in Yorkshire; 7% is used as recycled aggregate for building blocks near Pontefract, West Yorkshire; 4% is used for cement manufacture; and 1% is metal (e.g. from window frames) and is sold for recycling (Glass collector’s Quality Manager, personal communication, 08 June 2017). The rest of the diverse supply-chain actors contacted, did not provide comprehensive information either because they did not have it on their records or because this type of information might be considered commercially sensitive. Thus, commercial competence hinders knowledge and data sharing.

Some of the stakeholders seemed uneasy or even annoyed when asked about their waste management. For instance, a Strip-out Contractor’s Resource Manager (personal communication, 14 December 2017) was contacted via phone call in relation to one of the fit-out case studies. He showed a rude attitude and stopped the conversation when he was further questioned about waste, where the only information given was that waste from their de-fit projects was sent to a certain MRF. Therefore, an email was sent to this MRF copying in the Strip-out Contractor’s Resource Manager. The latter replied to this email right away saying he did not give permission to follow their waste. There was a clear reluctance from this stakeholder to provide thorough information or to allow somebody else to inquire about their waste management. He referred to the waste as “our waste”, implying that waste handling should not be a matter of public record.

When data was provided, there often was inconsistency of information between stakeholders. For instance, a Waste Contractor claimed they send a few waste streams to a certain MRF. This MRF was then contacted and said they have not received waste from that Waste Contractor for a long time. Likewise, another Waste Contractor stated they send plasterboard...
waste to a specific MRF, which was also stated on the information leaflet handed to their clients. Subsequently, the MRF was contacted and claimed they do not receive any type of gypsum waste. Situations like these demonstrate that there is no strict auditing or factual evidence showing that waste holders actually do what is stated. All of the contacted waste holders claimed over 98% of the waste they handle gets recycled (since this seems as a standard for commercial competitiveness), however, none of these waste holders could provide factual evidence on this claim.

In line with this, many stakeholders across the supply chain were unaware of the waste final destinations, and the generally available data does not reflect the quality of the recycling output that may occur (Nelen et al., 2014). Eurostat (2018) database provides information on end-of-life treatment for different product categories, such as proportions of waste that is reused (in a few cases), recycling, incineration and landfilling. However, there is no data about the recycling output, e.g. what do building components and materials get turned into when recycled. It is difficult but important for improving resource efficiency, to develop databases at a local, regional and possibly global scale that fully cover the paths of waste streams until they become something else. Comprehensive information on the recycling of building products is crucial for identifying recycling (or reuse) barriers and opportunities to reduce C&D waste, as well as for supporting better design innovation on products to allow for higher resource circularity.

Under the current waste management scheme, it is unfeasible to know for certain the path or destination of specific items or material. However, stricter or better designed regulations would potentially allow the collection of more and better information on waste management. For instance, the General Contractor could provide a document certifying the path and destinations of waste, which could serve as a proof for assessment or certification methods. This certifying document should consider the whole path followed by waste streams across the supply chain. Accordingly, the people in charge of final destinations need to provide the corresponding partial certificate to the Waste Dealers, the Waste Dealers would in turn provide their partial certificate to the Waste Contractor, and the Waste Contractor would then provide the complete certifying document to the General Contractor. The certifying document may include, kilometres travelled and the actual final uses of waste materials or products. This process may be a bureaucratic challenge, but digital technology such as that used for tracing the provenance of meat in the food industry (Mousavi, 2002; Yordanov and Angelova, 2006) may be an example to use as a base to develop such a method.

The path followed by waste could be traced in at least two different ways:

1. Observed path: this is defined as waste moves along the supply chain. To carry this out, one must trace the batches containing the waste or items under consideration, although this might be complicated.
2. Expected path: this is defined before-hand based on the respective stakeholders’ suppliers (e.g. the suppliers who receive waste from the Waste Contractor and so on). To achieve this, certain information that is currently considered commercially sensitive should be made available. For instance, each stakeholder should clearly specify
the suppliers they are sending the waste to at a given time and the suppliers in charge of the final destinations should specify what they do with the waste they receive.

5.6.3 Government regulation

There are opportunities to enhance governmental regulation on waste management during fit-out projects. First, waste streams from fit-outs get recorded in EWC codes which oversimplify the information and often do not reflect what building materials or components these codes relate to. The waste classifications should be made fully compatible with wastes found in building fit-out or refurbishment projects, and items such as ceiling tiles or electrical sockets should be associated with a specific code.

From involvement in fit-out case studies and interviews with supply-chain stakeholders, it was found that a proper standard on waste treatment is missing in the UK. All waste holders must have an operating permit from the EA (DEFRA, 2016); this might be a waste management permit or waste-carrier license. However, without a standard (and strict auditing) there is no way of knowing that the waste firms are doing exactly what they claim to do (Waste Contractor’s Quality & Resource Development Manager, personal interview, 26 May 2017).

The EA, as part of the Department for Environment, Food and Rural Affairs (DEFRA) seems to disregard the stakeholders in charge of recycling or treating the waste. For example, the Waste Duty of Care Code of Practice (DEFRA, 2016) presents and defines the stakeholders involved with waste production, transport, trading, and handling (as seen in subsection 2.4.6); however, there is no careful consideration for the stakeholders in charge of transforming or treating the waste. Therefore, there is no actual information on the recycling output in the UK, i.e. what precisely waste gets recycled into or used for.

In the case of gypsum, the EA has imposed a special end-of-life treatment for gypsum-based products since 2009. Products such as plasterboard are required to be closed-loop recycled or landfilled in a separate cell away from biodegradable waste to avoid the production of hydrogen sulphide (UK Government, 2010). This restriction has encouraged the segregation of plasterboard at construction sites or Transfer Sites, as seen in the fit-out case studies presented here (in subsections 4.4.3.5, 4.4.4.5 and 4.4.5.5), which facilitates the measurement and tracing of this particular waste stream.

Higher rates of reuse, remanufacturing and closed-loop recycling could be encouraged through financial incentives or tax breaks (APPSRG, 2014; European Commission, 2017). In line with this, a possible way to encourage higher rates of remanufacturing is to reduce or eliminate labour tax on remanufactured goods. This tax reduction could be offset by taxing resource consumption, possibly based on a scale of the cycles in which resources are used, i.e. remanufacture, recycling, extraction. The tax break on remanufacturing must be linked to the end-of-life units that a company reclains, partly so that there is less room for fraud; e.g. a company can only claim tax breaks on the units they have legitimately reclaimed and remanufactured. For this to be feasible there must be solid auditing and inventorying on the flows of building components (or any products) at city or country level. Therefore, building components must include an identifier such as an RFID or a unique alphanumeric code. The number of times that a product gets remanufactured could be registered in the corresponding identifier.
5.7 Particular issues in fit-out case studies

5.7.1 Introduction to this section
Particular issues encountered during fit-out case studies are discussed next. Subsection 5.7.2 summarises the tendency of the decision and material flows during fit-out processes, and subsection 5.7.3 highlights the circular pathways followed during UCL fit-outs. Subsection 5.7.4 provides an in-depth discussion on the procedure conducted at one of the fit-out case studies to salvage building components.

5.7.2 Decision and material flows in fit-out case studies
In terms of decision flow, the supply-chain structure was similar for the UKGBC offices, UCL Confucius Institute and UCL Central House fit-outs. However, the supply chain at the UKGBC offices fit-out was slightly different since there was no Strip-out Contractor involved in this fit-out project and the General Contractor was in charge of both the de-fit and re-fit stages. The fit-out at Conduit Members’ Club showed a different supply-chain structure than the other fit-out projects, due to the involvement of a Reuse third party, which was in communication with the Re-users (as detailed earlier in subsection 4.4.6.6).

The Design Team had the most communication links at both the Bank offices and the UKGBC offices fit-outs. At UCL Confucius Institute and UCL Central House fit-outs, the General Contractor showed the most communication links within the supply chain. At Conduit Members’ Club the Reuse third party along with the General Contractor presented the most communication links. These supply-chain actors holding more communication links could potentially function as communication nodes. However, in practice this was not the case and the supply chain generally showed a discontinuity of communication, as discussed in subsection 5.6.2.

The analysed fit-out processes generally showed a linear material flow across the corresponding locations in the path followed before reaching the final destinations. Divergently, Conduit Members’ Club fit-out was the only case study in which the material flow showed a non-linear deviation, where salvaged building products were taken to a yard before being collected by Re-users.

5.7.3 Circular pathways in UCL fit-out case studies
One of the major challenges for future UCL fit-out projects entails achieving higher reuse rates of removed building components. According to the UCL Estates Strategy Manager, UCL is more focused on the new building components to be installed than on the salvaging or treatment of the removed components. The reuse rate of components is mostly driven by cost-benefit criteria (UCL Estates Strategy Manager, personal interview, 05 October 2017; UCL Waste Manager, personal interview, 15 November 2017; Wilson James’s Senior Logistics Manager, personal interview, 26 October 2016). Moreover, it is difficult to persuade faculties or departments to use second-hand furniture as they have expectations for their building fit-outs and prefer new products rather than reused. One example of reluctance towards reuse is the Law Department at Bentham House, where they refuse to get reused furniture as they wanted a “high-end space”. An opposite situation is the Bartlett Faculty of the Built Environment at Here East, where they are keen to get reused furniture as it will be
used for heavy-duty practices (UCL Waste Manager, personal interview, 15 November 2017).

Another issue at UCL is that each fit-out or refurbishment project is isolated and just “looks after itself” (UCL Sustainability Officer, personal interview, 10 October 2017), and fit-out project officers and Project Managers do not communicate sufficiently among each other (William James’s Senior Logistics Manager, personal interview, 26 October 2016), and also institutional knowledge fades over time. Therefore, UCL might store some building components for 18 months and then totally forget about it (Williams James’s Senior Logistics Manager, personal interview, 26 October 2016). Unfortunately, PRAs are not a customary process for UCL fit-outs (UCL Estates Strategy Manager, personal interview, 05 October 2017), but these practices may significantly support higher reuse rates for building components.

Finally, having to recycle based on a target percentage might not be the best way to go as this system has space for fraud (UCL Sustainability Officer, personal interview, 26 September 2016). Waste management companies involved in UCL fit-out projects claim they recycle over 90% of the waste they collect but they do not break it down, so there is no way to know precisely what happens to the waste.

At the UCL fit-out case studies, most of the removed building materials and components were collected by Waste Contractors, so UCL (the Client) lost both the material and functional value of the removed building products. However, a small share of the building components (relative to the totality of removed items) did follow circular pathways, as detailed next.

At UCL Confucius Institute fit-out, some of these elements were retained due to heritage criteria, as was the case for the interior partitions, where more time and effort were required to adapt these elements for purpose than it would have taken to demolish them and build new partitions. It is worth mentioning that the retained wall tiles blended with the new components and this mixture created an aesthetically pleasing environment. Likewise, the retained floorboards looked as new after sanding and matched well in the newly refurbished space, although these floorboards were originally under the carpet tiles. Both the retained wall tiles and floorboards within the finished fit-out can be appreciated in Figure 4.18.

At UCL Central House fit-out, all furniture (i.e. lockers, chairs and workstations) were stored at UCL’s storage site along with more than half of HVAC ceiling cassettes. Storage of components, in this case, is not necessarily a circular pathway as it relies on a future outcome, in which building components can eventually be reused but can as well get disposed of. In fact, many of the items at UCL’s storage sites get forgotten and ultimately discarded (Williams James’s Senior Logistics Manager, personal interview, 26 October 2016). The design of exposed services in this case study potentially allows for independent modification without interfering with the cladding layer (such as ceiling tiles). Conversely, the acoustic spray applied on the ceiling seemed as a feature with poor circularity as it inhibits non-destructive removal and subsequent reuse.
5.7.4 Salvaging of building components from Conduit Members’ Club

Out of the analysed case studies, Conduit Members’ Club fit-out was the only one in which the Client chose not to follow an assessment or certification method as it was deemed that such schemes constrain the sustainability approach to limited alternatives and *modus operandi*. Ironically, this was the fit-out case study that showed the highest rate of salvaging of building components, in which offsite reuse was the predominant circular pathway. The salvaged building components were allocated to Re-users before the de-fit stage, similar to the practice conducted by Rotor DC (2019).

The supply-chain actors with highest involvement in the process for salvaging building components were the Design Team’s Sustainability Consultant, the Reuse third party’s Owner/Director and the Strip-out Contractor’s Site Manager, but the driver for this approach being taken was the progressive Client and the relationship between the Sustainability Consultant and the Client (Design Team’s Sustainability Consultant, personal interview, 04 August 2016; 14 October 2016).

The Reuse third party, Globechain, was an unusual and relevant supply-chain actor. Globechain helped to reinforce the communication among supply-chain stakeholders, as well as involving Re-users, which reclaimed buildings components for further reuse. Accordingly, Globechain had high involvement in both the fit-out process and the waste management process, positioning this actor in quadrant b of the quadrant-divided supply chain (shown in subsection 5.2.1), where usually no stakeholder appears.

The Strip-out Contractor performed a special role in which they were more involved than usual in the fit-out and waste management process, shifting this contractor to the centre of the quadrant-divided supply chain (see subsection 5.2.1). The Strip-out Contractor had to take additional care when removing items, implying more time and higher costs, so a premium was charged to the Client.

Some issues that emerged from the planned procedure for salvaging building components included that the items sometimes looked less appealing after removal, and the fact that some Re-users changed their mind about wanting the items. Risks involved in this procedure entailed that items could get damaged during removal and transportation, deteriorating products’ aesthetics or causing items to malfunction. The latter is a potential hazard in the case of building components such as electrical equipment (fluorescent lights, sockets) or compressed units (fire extinguishers, some appliances). Complications during removal also included that the timber floor tiles were stuck on the plywood backing, and many of the tiles broke during the removal process and were thus not salvaged. Similarly, the marble wall panels were glued to the wall and some of them broke when removed. Glazed partitions could not be taken out through the staircase due to their large size, so they were taken out through the window with a hoist, supported by the scaffolding outside. There was also the issue of the final destination of salvaged items, as supply-chain stakeholders can be held accountable for inappropriate or illegal management of reclaimed items. For instance, a Re-user could eventually fly-tip (illegally dispose of) a particular item.
The challenges encountered during the salvaging procedure were affected in different dimensions. Space, time and transportation represented logistic challenges. Technical difficulties included the non-destructive removal of building components and understanding the different elements of an unusual de-fit process. Coordinating the involved supply-chain actors was an important organisational barrier, while the behavioural dimension entailed the General and Strip-out Contractors’ resilience to an unconventional procedure and the Re-users reliability.

The procedure for salvaging of building components presented here can be carried out in further fit-out projects. Some practical recommendations for improving this procedure include: conducting a comprehensive PRA inventory prior to the de-fit process (including items’ dimensions and photographs); starting the ‘open days’ in a more timely fashion (refer to subsection 4.4.6.6); recording and auditing the whole process as it relies on several supply-chain actors; maintaining good communication among these actors; and tracing salvaged items to confirm the Re-users are actually doing what was stated.

5.8 Towards more circular building fit-out

5.8.1 Introduction to circular building fit-out

Arising from this work it is clear that circular building fit-outs are those with circular material flows, in which building materials and components are “circulated at their highest utility at all times” (EMF, 2015b). Circular pathways for building products include retaining, reuse, remanufacture, and closed-loop recycling, as illustrated in Figure 5.12.

![Figure 5.12: Diagram of a circular building fit-out (author generated).](image)

Among the different dimensions around circular fit-outs, the technical and organisational aspects that underpin circularity are particularly crucial. The following are aspects to consider for all fit-out projects:

- Conducting a PRA inventory would allow to identify potential circular pathways for building products.
- Modularisation and size standardisation would increase the circularity potential of building materials and components.
• Designing for disassembly (Morgan and Stevenson, 2005; Guy and Ciarimboli, 2006) facilitates non-destructive removal of building materials and components.

• Reverse logistics (Souza, 2013; WEF 2015) and asset tracking (Ness et al., 2014; BAMB, 2018; EPEA, 2018) facilitate recovering the value of removed building products.

• Concepts such as open building, designing in layers or designing for adaptability (Habraken, 1972; 1998; Brand, 1994; Cheshire, 2016) entail that building spaces (and structures) should be designed to allow the replacement of a building layer or system without affecting other layers.

5.8.2 Building fit-out layers
Building fit-outs can be divided into different layers, which are different from the building shearing layers proposed by Brand (1994). Figure 5.13 presents the 11 fit-out layers associating them with the six shearing layers that make up a whole building. As can be seen, the shearing layer of Stuff includes the fit-out layers of Furniture, Appliances, Kitchen/Toilet and Signage; Space plan can be divided into Finishes, Insulation, Internal Cladding and Infill Structure; Services comprise Lighting and Services; and the shearing layer of Skin includes the fit-out layer of Openings (such as doors and windows).

Like the building shearing layers, fit-out layers should also be designed to allow the independent modification and material flow in one layer without affecting the other layers. The coding of building components used for the PRAs conducted in this work is based on these

![Figure 5.13: Independently modifiable building fit-out layers, associated with the building shearing layers proposed by Brand (1994) (author generated).](image-url)
layer categories. Refer to Table 3.3 to see the defined code categorisation and the types of building products which were included in each fit-out layer.

5.8.3 Opportunities and barriers for circular fit-out

5.8.3.1 Introduction to opportunities and barriers for circularity in fit-outs

In the following subsections, circular fit-out opportunities and barriers are summarised and classified into six different dimensions: economic [ECO], regulatory [REG], informational [INF], technical [TEC], organisational [ORG] and behavioural [BEH]. These dimensions are based on Pomponi and Moncaster (2017) and adapted to include all listed opportunities and drivers. When an aspect relates to more than one dimension, the corresponding code is added at the end of the sentence to indicate the other dimension(s) it relates to. The information shown below was compiled from personal interviews, observations conducted during case studies and the literature review.

5.8.3.2 Economic

Barriers:
- There are weak economic incentives to foster the transition towards a circular economy practice (Su et al., 2013).
- Virgin material can be cheaper than reused/recycled material partly due to the environmental cost not being internalised in the price of virgin material (European Commission, 2014a).
- Waste collection is one of the major costs associated with waste management (WRAP, 2011).
- There is no market of scale for disassembled components and recycled materials [ORG].

Opportunities:
- Costs and finance are overall the main criteria in the decision-making process and thus represent a strong incentive for circular practices (Design, Engineering and Business Consultation Company’s Senior Engineer & Consultant, personal interview, 27 November 2015).
- Align mechanisms and incentives so the Client or the respective stakeholders benefit by selling their segregated waste or at least by not having to pay for waste collection or disposal (Waste Management Company’s Owner/Director, personal interview, 29 June 2016).

5.8.3.3 Regulatory

Barriers:
- There is a lack of a standard system for performance assessment of building fit-outs and there is poor enforcement of legislation (Su et al., 2013).
- Current assessment methods do not appropriately measure the circularity of materials and components, as these methods cannot address whether a product will be reused or recycled (Ding, 2014) [INF].
- There is no direct connection between the start-point of waste (wherever waste is generated) and the end-point (where waste gets processed into new materials) (Waste...
Management Company’s Owner/Director, personal interview, 29 June 2016) [ORG].

- The current regulatory framework in the waste management industry can be improved to better identify the paths and final destinations of waste and thus be able to design mechanisms to increase resource circularity.

**Opportunities:**
- Complement building codes with ratings and targets that are capable of assessing the environmental performance of a building fit-out from a life-cycle perspective.
- Increase landfill taxes to encourage actors in the supply chain to engage in circular practices (Waste Management Company’s Owner/Director, personal interview, 29 June 2016). [ECO]
- Eliminate labour tax on remanufactured goods. This can be offset by creating new taxes on resource consumption [ECO].
- Make EPR mandatory or widespread for building products and establish PROs to support it [ORG].

5.8.3.4 **Informational**

**Barriers:**
- There is a lack of reliable information related to the offer of sustainable building materials and components, which hinders their widespread use (Guerin and Ginthner, 1999 as cited in Moussatche, 2002).
- It is sometimes challenging to properly apply assessment methods in developing countries since the climatic, environmental and social criteria might be different, while the available information on building products may be insufficient (Certification Development Manager, personal interview, 23 January, 2016) [REG].
- EWC codes are not fully compatible with building components and materials found in fit-outs [REG].

**Opportunities:**
- Offer accessible on-line databases with information about available sustainable or circular building products to increase their accessibility and use.
- Make EDPs mandatory or widespread and support their standardisation to allow for better comparability.
- Integrate building products with a “material passport” or identifier, such as RFID (Ness et al., 2014) to track available stocks, support the creation of material inventory software (EMF, 2015a), and consider available stocks in the design of new building projects [TEC].
- Make use of the IoT as a support to inventory and track building products as intelligent assets [TEC].
- Specify the purpose and performance of the end-products by manufacturers, and specify the input materials (EMF, 2015b).
- Manufacturers should also state the average lifespan and the availability of spare parts of building products and declare their circularity potential by stating whether a product can be repaired, reused, remanufactured or closed-loop recycled.
5.8.3.5 Technical
Barriers:
- Visual deterioration is an important barrier to reusing building components [ORG].
- Non-destructive removal is often difficult or time and labour consuming.
- Some removed building components might get damaged during transportation.
- The repair and testing procedures of building components may be complicated practices to carry out efficiently (Interior Design Company’s Design & Sustainability Director, personal interview, 07 November 2015).
- Unavailability of spare parts may reduce the lifespan or reusability of some building components.
- The lack of standardisation in building components complicates their reuse in subsequent fit-out projects [REG].
- Several building materials and components must be cut to fit purpose, limiting their reusability, and there is some uncertainty on what to do with onsite offcuts.
- It is currently more cost-effective to recycle metal-based components than reusing them.
- The export of waste reduces the local investment in infrastructure and the innovation in technology for recycling.

Opportunities:
- Design for adaptability to attain flexible interior spaces that can be adapted or modified for different uses without the need of a fit-out.
- Consider the different fit-out layers and design fit-outs accordingly to allow the modification or replacement of a fitout layer or system without affecting other layers, e.g. exposed services layer independent from the cladding and finishing layers or modular cladding independent from the stud frame structure.
- Employ interior building envelope materials that do not require a finishing layer (e.g. polished concrete or engineered wood).
- Design the lifespan of building components according to their rates of replacement (Rossi and Deepak, 2009) and/or based on the intended or expected end-of-life pathway (Pongrác and Pohjola, 2004).
- Establish a market of scale for testing and repairing products to reduce costs. The testing and repair procedure can either be done by the manufacturer, the distributor or a third party.
- Ensure availability of spare parts, if required, to support higher rates of repairing and reusing.
- Design modular and size-standardised building components that can be easily reused in subsequent building projects [REG].
- DfD to facilitate non-destructive removal of materials and components (EMF, 2015b). Demountable building products should be designed with connections such as reusable bolting, zip-locks, snap-fits or clipping.
- Substitute materials that are difficult to reuse and recycle, with non-toxic, sustainable alternatives (EMF, 2015a).
• Define and use a standard colour-coding for wheelie bins or skips to encourage and facilitate onsite waste segregation and equip waste-collection vehicles with cages, compartments or sections to keep apart the segregated waste.

• Develop criteria for manufacturing that consider possible useful applications of by-products and wastes (EMF, 2015b) from their own process or from the process of other manufacturers, industries or economic sector [ORG].

5.8.3.6 Organisational

Barriers:
• There is a disintegrated supply chain in which each player naturally maximises their own profit at the expense of the others (EMF, 2015a) [ECO].

• There are generally too many companies involved in the resource/waste management in fit-out projects (Waste Contractor’s Environmental and Sustainability Manager, personal interview, 21 October 2016).

• Logistics, both transportation and storage, is one of the main barriers/concerns. Transportation can be costly and carbon intensive, while there is a conceived lack of storage space for reusable goods, which makes reuse of components more difficult (Construction Logistics Company’s Senior Logistics Manager, personal interview, 26 October 2016; Waste Contractor’s Quality & Resource Development Manager, personal interview, 26 May 2017).

• Normally, new building components are specified at the upper levels of the supply chain, leaving a limited margin for reuse opportunities (Waste Contractor’s Quality & Resource Development Manager, personal interview, 26 May 2017) [BEH].

Opportunities:
• Start engaging with circular measures from the design stage to facilitate achieving a high rating in any assessment tool.

• Support multi-directional decision flows within the supply chain to improve the circularity of the material flow. Certain supply-chain stakeholders could act as communication nodes for the involved supply chain, with the aim of keeping the fluidity and continuity of information [INF].

• Conduct PRAs prior to the fit-out process, so that more elements can be retained, reused or closed-loop recycled (Waste Contractor’s Environmental and Sustainability Manager, personal interview, 21 October 2016) [REG, INF].

• Installed building products planned for removal can be allocated to Re-users before the de-fit stage to save on logistic costs, possibly supported by Reuse third parties or sharing platforms.

• Conduct detailed inventories of installed and stored building components at institutions (e.g. UCL) to keep track of the available stock and consider it in the design of future fit-out projects at that or other similar institution [INF].

• Set up reverse logistics systems or take-back schemes (supported by material inventories and material identifiers) either through the Supplier (manufacturer or distributor) or through RCLR third parties.
• Integrate the supply chain (the Client, Design Team, Fit-out and Waste Contractors) to share costs and benefits of end-of-life product circular pathways (European Commission, 2014a) [ECO].

• Involve the waste management supplier or Waste Contractor in the fit-out project before the strip-out stage, to facilitate better onsite material segregation and to support the initial set up of end-of-life and take-back schemes (Waste Contractor’s Quality & Resource Development Manager, personal interview, 26 May 2017).

• Implement new business models. Trade-in programs, leasing (e.g. lux-hours instead of light fixtures) or relicensing fees are possible circular consumption models (Souza, 2013) [BEH].

5.8.3.7 Behavioural

Barriers:

• There is a common belief that remanufactured, reengineered parts and recycled materials have an inferior quality than new ones (Andrews, 2015).

• People generally tend to prefer new products rather than reused, often driven by the desire of status (UCL Waste Manager, personal interview, 15 November 2017).

Opportunities:

• Change people’s mindset towards reused items and involve government and leaders of public opinion in more circular practices so that this becomes a trend.

• Incentivise the Client to choose or pursue circular practices or to use an assessment method as guideline (Waste Management Company’s Owner/Director, personal interview, 29 June 2016) [ORG].

5.8.4 Specific barriers to reuse of building components

The barriers to reuse which relate to all building components and were present at all fit-out case studies were: space, time (Morgan and Stevenson, 2005; Guy and Ciarimboli, 2006), transportation, finding Re-users and additional costs incurred. However, from the analysis of the fit-out case studies, it was observed that there were different specific barriers to reuse depending on the type of building component in question. Table 5.3 covers the encountered barriers to reuse along with the corresponding building components that relate to each of these barriers.

A total of 39 building components were selected for the analysis in this subsection. These were considered as components commonly found in building fit-outs, based on the involvement with fit-out case studies. A list including these building components is presented in Table 3.3 in subsection 3.2.4.

Figure 5.14 shows the percentage of building components that relate to each reuse barrier. The reuse barrier of ‘lack of size standardisation’ related to 36% of the analysed components, followed by ‘no modular assembly/installation’, which related to 31% of the components. It is worth noting that the barriers of ‘material was cut to fit purpose’ and ‘difficult non-destructive removal’ might both be associated to the issues of size-standardisation and modular assembly.
Table 5.3: Barrier to reuse that relate to different building components (author generated).

<table>
<thead>
<tr>
<th>Barrier to reuse</th>
<th>Examples of building components affected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of size standardisation</td>
<td>carpet tile, ceiling tile, door, floor finish, floor outlet, furniture, glazed partition, HVAC unit, light fitting, RAF, wall finish, window frame, window pane, window blinds/curtain</td>
</tr>
<tr>
<td>No modular assembly/installation</td>
<td>cableduct, ceiling tile rail, floorboard, furniture, glazed partition, HVAC ductwork, kitchen counter/cupboard, plasterboard, shelves, stair balustrade, stair handrail, wall moulding</td>
</tr>
<tr>
<td>Visual deterioration or aesthetics</td>
<td>carpet, carpet tile, ceiling tile, furniture, floor finish, kitchen counter/cupboard, sink, stair balustrade, stair handrail, toilet bowl/urinal, window blinds/curtain</td>
</tr>
<tr>
<td>Safety issues or need of testing</td>
<td>audio-visual systems, appliance¹, boiler, cable, fire alarm, fire extinguisher, HVAC unit, light, light fitting, insulation, socket²</td>
</tr>
<tr>
<td>Material was cut to fit purpose</td>
<td>cable, cableduct, carpet underlay, floorboard, insulation, plasterboard, wall moulding</td>
</tr>
<tr>
<td>Difficult non-destructive removal</td>
<td>carpet, ceiling tile rail, floor finish, floorboard, kitchen counter/cupboard, plasterboard, wall finish</td>
</tr>
<tr>
<td>Material value higher than functional value</td>
<td>boiler, cable, ceiling tile rail, HVAC ductwork, radiator, RAF</td>
</tr>
<tr>
<td>Potential damage during transportation</td>
<td>ceiling tile, glazed partition, light, light fitting, window pane</td>
</tr>
<tr>
<td>Unavailability of spare parts</td>
<td>appliance, audio-visual systems, RAF</td>
</tr>
</tbody>
</table>

¹ Appliances include dishwasher, fridge, microwave, stove/oven, among other.
² Sockets include electrical socket, ethernet socket, electrical socket, among other.

Figure 5.14: Percentage of building components that relate to each reuse barrier, based on 39 analysed components (author generated).
5.8.5 Circularity assessment in building fit-out

A basic method for assessing the circularity of building fit-outs is proposed in Table 5.4. As in the case of the PRA inventories presented earlier, the ‘item’ refers to the building component or material (e.g. window blinds, ceiling tile, plasterboard); the ‘code’ for each type of item is given in Table 3.3, and the ‘quantity’ indicates the amount of items and can be given in units, metres or square metres depending on the type of building material or component. The ‘mass per unit’ represents the mass (in kilograms) per unit, metre or square metre of each item; the ‘total mass’ is the mass of all units of each item and is given by multiplying the ‘quantity’ by the ‘mass per unit’. The Environmental Impact Factor (‘EIF’) is explained below. The Environmental Weight (‘EW’) is given by multiplying the ‘total mass’ by the ‘EIF’. The Circular Environmental Weight (‘CEW’) is the amount of the total ‘EW’ of the item that follows a circular pathway.

Table 5.4: Proposed basic method for circularity assessment in building fit-outs (author generated).

<table>
<thead>
<tr>
<th>Item</th>
<th>Code</th>
<th>Quantity</th>
<th>Mass per unit [kg]</th>
<th>Total mass [kg]</th>
<th>EIF (per kg)</th>
<th>EW</th>
<th>Circular pathways</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carpet tile</td>
<td>F1 02</td>
<td>926</td>
<td>1</td>
<td>926</td>
<td>0.5</td>
<td>463</td>
<td>Retain</td>
</tr>
<tr>
<td>Ceiling tile</td>
<td>CL 01</td>
<td>489</td>
<td>1.2</td>
<td>586.8</td>
<td>0.2</td>
<td>117.4</td>
<td></td>
</tr>
<tr>
<td>Light fitting</td>
<td>LI 01</td>
<td>72</td>
<td>0.4</td>
<td>28.8</td>
<td>0.4</td>
<td>11.5</td>
<td></td>
</tr>
<tr>
<td>RAF</td>
<td>CL 04</td>
<td>747</td>
<td>9</td>
<td>6,723</td>
<td>0.03</td>
<td>201.7</td>
<td>188</td>
</tr>
<tr>
<td>Socket:</td>
<td>SE 12</td>
<td>14</td>
<td>0.2</td>
<td>2.8</td>
<td>0.6</td>
<td>1.7</td>
<td></td>
</tr>
<tr>
<td>electrical</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>795</strong></td>
<td></td>
<td><strong>188</strong></td>
<td></td>
</tr>
</tbody>
</table>

The options for circular pathways include ‘retain’, ‘reuse’ and ‘reman’ (remanufacture). According to the circular–economy waste treatment hierarchy (see Figure 2.4), retaining is the most favourable (or environment-friendly) option, followed by reusing and remanufacture. Although a weighting factor could be applied to these circular pathways, this basic method considers these options as equally circular. Recycling is not considered as a circular option in this case, as the recycling output may be uncertain. If the assessment were based on the life-cycle of a building fit-out, other parameters could be included apart from the end-of-life alternatives, such as a utility factor to account for the length and intensity of the building products’ use (EMF, 2017a; 2017b).

The EIF is a dimensionless index of the environmental impact per kilogram of each type of building material and component. It might be complex to define EIFs for each type of building product, however, it is necessary to establish such an indicator to make the assessment objective, as mass and volume alone are both subjective parameters (as earlier discussed in subsection 5.6.1). The EIFs could be obtained from LCAs (or EPDs) conducted for each type of item, based on a standard set of products. To obtain a single index, LCA endpoint indicators can be weighted and integrated into a single index before being normalized per mass (in kilograms) to obtain the respective EIF. Endpoint indicators, such as the ones used in the ReCiPe model (RIVM, 2019), can assess the environmental impact of a product or
system from a comprehensive approach, including damage to human health, damage to ecosystems and damage to resource availability. These three endpoint indicators can be integrated into a single index as proposed by Itsubo and Inaba (2012), for instance.

The ratio of circularity (RC) of an entire building fit-out can be then given by dividing the total CEW by the total EW. A fit-out project where the entirety of the EW followed circular pathways would obtain a RC of 1, whereas a RC of 0 would represent that none of the EW followed circular pathways. The threshold to determine whether a building fit-out is circular could be set above a RC of 0.5.

Table 5.4 is filled with data from one of the fit-out case studies (UCL Central House). This example assumes that only five types of components were found in the fit-out project. The EIFs are proposed for illustrative purposes, as these indicators are not yet available in the literature. In this example, a RC of 0.24 was obtained, which means 24% of the fit-out project’s EW followed a circular pathway. This is the case as RAF accounted the largest share of the EW, and 93% of RAF was retained in situ. An interesting point in this example is that the retained RAF accounted for 76% of the total mass, considering all building components, but it represented only 24% of EW. This method, although presented here in a basic form, can be further developed to indicate which building products are more convenient to retain, reuse or remanufacture to avoid the highest environmental impacts.
6 Conclusions

6.1 Introduction to conclusions
The main objective of this work was to identify potential improvements in the fit-out process and in the design of building components, aiming to make these practices more circular. A socio-technical analysis for office and higher education institution (HEI) building fit-outs was developed as a base for the identification of policy and practical recommendations. Mixed methods research was used to produce a description of particular fit-out projects and, to some extent, reflect on the overall fit-out industry in London. Qualitative methods included interviews with stakeholders selected through chain-referral sampling and corresponding qualitative analysis, as well as onsite observations recorded in an observational diary. Quantitative methodological tools comprised cross-examination of Waste Reports, pre-refurbishment audits (PRAs) and material flow analyses (MFAs). In total, 31 supply-chain stakeholders related to the fit-out industry were contacted and five fit-out case studies as well as two Waste Contractor case studies were analysed.

The set of research questions considered aimed to map out the stakeholders within the fit-out supply chain while defining their function and the relations among them, from a qualitative approach. The quantitative approach aimed to determine key materials and components in office building fit-outs, and to identify and measure the waste streams generated while tracing their paths and final destinations. Only material outflow (waste) was considered within the scope. Both qualitative and quantitative approaches were used to identify the key incentives that encourage circular building fit-outs, and the current and potential mechanisms that support them.

6.2 Conclusions and recommendations
Based on interviews and involvement with case studies, it was shown that the generic fit-out supply chain is composed of the Client, the Design Team, Suppliers (comprised by manufacturers and distributors), General Contractor, Strip-out Contractor (sometimes), Waste Contractor, Waste Dealers and final destinations. Actors in the background supply chain include Policy makers, Assessment methods developers, the Environmental Agency (EA) and Researchers. The Client was an influential actor as they can decide on the sustainability level of the fit-out project. The Design Team showed the highest impact on the decision making within the project design, covering decisions such as the specification of building materials and components and the management of waste, as well as scoping sustainable measures based on the Client’s requirements or assessment methods. In the cases studied, the Design Team seemed more cooperative when following alternative or circular procedures, while contractors showed less enthusiasm to implement or support them.

Most frequently, the fit-out supply-chain showed a predominantly linear tendency, where generally both decisions and material were unidirectionally transferred from the upstream side of the supply chain towards the downstream stakeholders. The linear tendency of the decision flow seemed to be a barrier for the circularity of the material flow.

It was also recognised that communication mainly took place between stakeholders that were adjacent in the supply chain, and there was generally no effective communication among
nonadjacent supply-chain actors. The upstream stakeholders, such as the Client, the Design Team and the General Contractor, were not tangibly involved with the waste management process and therefore were unaware of the waste paths and final destinations. On the other hand, the downstream stakeholders, such as the Waste Contractor, Waste Dealers and the actors in charge of the final destinations had negligible influence on the decision making in the fit-out process. Thus, waste management was a role mainly performed by the downstream side of the supply chain, and the waste-management system should be redefined so that it engages the whole supply chain or life-cycle of the fit-out, from the design stage and execution, to the end-of-life disposal. A “life-cycle waste management” is necessary for building products, to better connect the design stage with the disposal phase.

The supply-chain actors holding the most communication links within the corresponding supply chain could potentially function as communication nodes, with the aim of keeping fluidity and continuity of information. At both the Bank offices and the UKGBC offices fit-outs, the Design Team was the supply-chain actor with the most communications links. At UCL Confucius Institute and UCL Central House fit-outs, the General Contractor showed the most communication links, and at Conduit Members’ Club the Reuse third party along with the General Contractor presented the most communication links.

At the Conduit Members’ Club fit-out, the Reuse third party did act as a communication node as this actor helped reinforce the communication among supply-chain stakeholders and involved Re-users, which reclaimed building components before the de-fit (strip-out) stage. Accordingly, the Reuse third party showed high involvement in both the fit-out process and the waste management process. The Strip-out Contractor also acted as a communication node, to some extent, as this stakeholder performed a special role to salvage building components, in which they were more involved than usual in the fit-out and waste management process, and thus they charged a premium to the Client.

Stakeholders with high involvement in both the fit-out and the waste management process represent an opportunity to increase the material circularity, but these stakeholders are normally absent in fit-out projects. Conversely, there are generally at least three stakeholders involved in the waste management, which entailed a gradual loss of information and posed environmental impacts due to transportation. To make the process more efficient, waste at the Building Site or Transfer Site could be collected by a remanufacture and closed-loop recycling (RCLR) third-party, a specialised collector who in turn would deliver the “waste” back to the Suppliers.

Removed materials and components were considered and treated as waste, regardless of their condition, and recorded either as mixed waste or fell under a specific waste stream with a European Waste Catalogue (EWC) code that allows some recording and measuring of flows. However, there are generally no EWC codes for building components, which hinders the capability to quantify their flow. EWC codes should thus be fully compatible with wastes found in building fit-outs, and in the building sector in general, to have access to detailed material-flow information. Small items such as carpet tiles, ceiling tiles and light fittings should be designed for closed-loop recycling to allow recurrent replacement while reducing the environmental burden. Larger items such as raised access floor (RAF) or office furniture
should be designed with long lifespan and with availability of spare parts for proper maintenance or repair.

Although some suppliers offer take-back schemes for their building products, the interviewed contractors claimed they hardly use these schemes due to constraints such as minimum quantities or grades accepted, the limited lines of products included, and the waiting time involved for collection. Standardised extended producer responsibility (EPR) systems would encourage building product suppliers to offer more accessible take-back schemes. In the UK, there are some producer responsibility organisations (PROs) to support EPRs in the sector of batteries, electric and electronical equipment and packaging but none in the building sector.

Collating rates of waste generation (RWGs) obtained from fit-out case studies with those from the literature, HEI buildings fit-outs averaged a RWG more than twice as high as office buildings. Therefore, different RWG thresholds should be defined as assessment indicators, considering the different types of space (i.e. office or HEI). The discrepancy of RWGs between types of space remains an issue for further study, but it might be subject to the sort of building components and/or the density of installed components per floor area at each type of space.

The most widely used indicator for measuring RWGs is tonnes of waste per 100 m$^2$ of floor area. This indicator depends on the design and development of the fit-out project, but it also depends on the amount and types of materials and components installed in the building prior to fit-out, which makes this indicator biased. Moreover, mass alone is a subjective parameter considering that the environmental burden of the diversity of building products is not necessarily determined by mass. Environmental impact factors could be developed, possibly based on life-cycle assessments (LCAs), to allocate a more objective environmental burden to building products.

Mixed waste was the top waste stream for both the fit-out and Waste Contractor case studies, while plasterboard, hardcore and wood were within the top-five waste streams in all cases. The “gate fee” for mixed waste is generally the highest, followed by plasterboard and wood, while segregated hardcore, metals, plastics, and paper/cardboard can be collected free of charge or even paid for. Although segregating waste at the Building Site is advisable for reducing Waste Contractor fees, the ratios of onsite waste segregation (ROWSs) showed to be generally low (62.5% in average) based on four case studies. Higher ROWSs would probably allow higher rates of high-quality recycling, due to less risk of cross-contamination and diminished material losses during the segregation process at Transfer Sites and/or MRFs. Measures that encouraged onsite waste segregation included the use of colour-coding for wheelie bins and equipping waste-collection vehicles with cages, compartments or sections to keep apart the segregated waste.

A high rate of landfill diversion was claimed by waste holders in the analysed fit-out case studies (91% - 99%). The high rates of landfill diversion encountered are likely related to the Landfill Tax in the UK, as handing the waste to a Waste Contractor is normally cheaper than direct landfilling. Landfill taxes seem to be convenient and should be maintained or implemented as needed. There was, however, some subjectivity in the actual rates of landfill
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diversion due to a lack of both strict auditing and available information. It was concluded
that material losses during recovery processes are not properly accounted for, and measures
should be taken to amend this shortcoming.

The availability and comprehensiveness of information decreased as material became waste
while passing through the supply chain. This means that the closer to where the waste han-
dling occurred, the more reluctant actors were to share information. Out of the contacted
waste holders (i.e. Waste Contractors, Waste Dealers and final destinations), only one of
them was able or willing to provide detailed information about the recycling output of the
Corresponding waste streams. The rest of the diverse supply-chain actors contacted did not
provide comprehensive information either because they did not have it on their records or
because this type of information might be considered commercially sensitive, and there often
was inconsistency of information among stakeholders within the same supply chain. Thus,
commercial competition proved to be a barrier for knowledge and data sharing, although
information on waste handling should be a matter of public order.

Moreover, generally available data at a national and European scale does not report the qual-
ity of the recycling output (i.e. what precisely waste gets recycled into or used for). An effec-
tive regulatory framework in the waste management industry would increase the access and
availability of waste handling information (e.g. waste paths and final destinations), and it
would support the identification of barriers and opportunities for higher resource circularity,
such as product design innovation.

MFAs conducted for fit-out case studies showed that most waste streams got downcycled
into products or uses that require inferior material quality, little waste got closed-loop recy-
cled into the same original product, while the remaining waste was used as fuel for energy,
and a small residual percentage was landfilled. Plasterboard was the only waste stream that
was (partly) closed-loop recycled, driven by UK regulations for gypsum-based products.

The relative high proportion of waste exported (35% - 61%) seen in fit-out case studies
represents a barrier to the local development of innovative technology and infrastructure for
recycling. The UK should thus invest in national recycling infrastructure, considering the
local and national waste recycling requirements. This would yield potential advantages such
as enabling stricter auditing of waste treatment procedures, reducing carbon emissions due
to waste transportation, and encouraging the development of innovative recycling tech-
niques.

In the conventional linear pathway, all removed materials and components are treated as
waste, which entails a loss of both their material and functional value. However, there are
alternative paths for end-of-life building products that entail savings in energy and carbon
emissions. These alternative or circular end-of-life pathways include: retain (*in situ*), onsite
or offsite reuse, remanufacture and closed-loop recycling. Storage of building components
for subsequent reuse is not necessarily a circular pathway as it relies on a future occurrence.

Circular end-of-life pathways were found to be relatively uncommon and there was uncer-
tainty about their financial and environmental benefits. Therefore, an indicator was designed
to evaluate the monetary or environmental convenience of reusing a specific building component instead of replacing it with a new one. The Relative reuse cost could be useful to calculate scenarios such as: for how long you can store an item or how far you can transport it, so the reuse option is convenient and/or cost-effective.

Each of the circular end-of-life pathways relates to different criteria and approaches. For instance, product lifespans and people’s acceptance of reused products relate to both retaining and reuse. Aspects related only to reuse involve: ease of removal, size standardisation and access to a market of scale for salvaged components. Elements associated with both reuse and remanufacture include asset tracking and reverse logistics. Issues which relate only to remanufacture include ease of disassembly of building products and tax breaks on remanufacturing. Issues concerning both closed-loop recycling and downcycling include recycling infrastructure and inventory of recycling output. The end-of-life pathways of retaining and reuse involve negligible waste generation, while the pathways of remanufacture, closed-loop recycling and downcycling require strategies for the reduction and regulation of wastes and emissions.

Assessment tools can support more circular practices in building fit-outs by preserving the value of removed materials and components and procuring building products with a high circularity potential.

Analysis methodologies such as MFA and LCA are useful assessment tools, although they overlook social and economic aspects and do not fully evaluate the circularity in fit-out projects. It is difficult to know whether a particular building product will follow a circular end-of-life pathway, as this only takes place in the future. Certification methods such as SKA Rating, BREEAM or LEED are loosely based on LCA and provide easy-to-use benchmarking, however, these methods may be costly and generally have low uptake at the moment. It was perceived that budget was usually the first priority for supply-chain stakeholders, followed by function, then aesthetics, and finally life-cycle sustainability. Therefore, financial incentives would encourage supply-chain stakeholders to pursue circular practices and/or to adopt assessment methods as guidelines.

It would not be advisable to make particular assessment schemes mandatory as this would encourage monopolising and it would constrain the users. During one of the analysed fit-out case studies, the Client decided not to follow a certification method since it was deemed that such a scheme may constrain the sustainability approach to limited alternatives and operating methods. It is also currently challenging to properly compare assessments of fit-out projects under different certification methods. Therefore, it is necessary to implement standard benchmarking indicators that a) are free and easy to use; b) allow for flexibility of sustainable alternatives and operating methods; c) are able to be objectively compared across different fit-out projects or assessment methods; and d) are capable of assessing the environmental performance of a building fit-out from a circular or life-cycle perspective.

PRAs should be inherent in any assessment method to inventory the installed building products before the de-fit stage and identify potential circular pathways for these products. As well, inventories should be conducted at institutions (e.g. UCL) to keep track of the available stocks and consider these in the design and development of new building projects. Material
passports or identifiers (e.g. RFID) and the internet of things (IoT) would facilitate cataloguing and tracking building products.

PRA inventories on existing fit-outs could be based on the independently modifiable fit-out layers, which include: openings, services, lighting, infill structure, internal cladding, insulation, finishes, signage, kitchen/toilet, appliances, and furniture. Like the six shearing building layers reported in the literature, the 11 fit-out layers should also be designed in a way that allows the modification or replacement of a layer or system without affecting other layers.

Opportunities and barriers for circular building fit-outs were identified and divided into six dimensions: economic, regulatory, informational, technical, organisational and behavioural. Barriers that particularly related to the reuse of building components included: space, time, transportation, finding Re-users and additional costs incurred. These barriers were associated with all building components and were present in all fit-out case studies. However, it was observed that there were different specific barriers to reuse depending on the type of building component. The main barriers to reuse were both the lack of size standardisation and the lack of modular assembly/installation. Building components should thus be standardised in size and designed with connections that allow easy, non-destructive removal.

At the fit-out case studies, mechanical obsolescence (defects due to lack of performance of materials or components) was seldom the reason for replacing building components, with some exceptions at UCL Confucius Institute fit-out, where the building had been unused for a long time and a few existing components showed a poor condition. The rate of replacement was generally shorter than the products’ lifespan, so the lifespan of building components should be designed according to their rates of replacement and according to the intended or expected end-of-life pathway. This may imply designing building components for a shorter lifespan and designing to make it easier to recycle, reuse or remanufacture these components after replacement.

On the other hand, psychological obsolescence (the desire for new products, although “old” ones still work) was a common reason for replacing building materials and components. It is thus advisable to provide financial incentives for supply-chain actors to use salvaged or remanufactured products and to change people’s mindset towards reused items; for instance, choosing salvaged items that can easily blend or contrast with new components, creating a more aesthetically pleasing space than if only new products were used.

6.3 Future work

- This work is based on five case studies of good-practice fit-outs of office and HEI buildings in London. To reduce the uncertainty in the results, further research should consider a larger sample of building fit-outs, including those conducted in other types of space (e.g. retail, restaurant, hospital) and fit-outs which follow average (or below-average) standards. The method defined and used for PRAs can be a useful research tool for subsequent research on building fit-outs.
- The financial value of material flows, including critical materials, should be considered in future research since the circular economy offers financial benefits that have not been widely studied.
• A study with a longer timeframe could follow the full life-cycle of a fit-out, from the installation of building products until their eventual removal and end of life. This work is presented with the expectation that an LCA would be conducted to assess the full environmental impact of building fit-out processes.

• Environmental impact factors for a set of standard building products can be developed based on LCAs or EPDs, aiming to develop an objective and comparable measure of the environmental impact of building products.

• A standardised measure for the circularity of products and processes and/or for the circularity potential of resources and products should be defined as a useful criterion for consumers and policy makers.

• Standardised fit-out benchmarking indicators should be developed to be able to objectively compare different fit-out projects, regardless of the assessment method used. This would support a more solid assessment framework for fit-out projects, ideally based on a circular approach. A possible example of this is the ratio of circularity (RC) proposed in this work, which can be further developed and tested in fit-out or refurbishment projects.

• Assessment thresholds should be defined for RWGs that are specific to each type of space (e.g. office, HEI, retail), based on the analysis of the average density of installation and the types of building products per type of space.

• To narrow the uncertainty about the socio-economic and environmental costs and benefits of circular end-of-life pathways, a holistic sustainability assessment of these pathways should be conducted. The indicator of Relative reuse cost proposed in this work can be a useful tool for assessing the environmental and/or financial convenience or reusing products, instead of buying new.

• When products are remanufactured, the ratio of the material preserved can be a criterion to reflect on the circularity of the remanufacturing processes.

• Contractors’ reluctance or resilience towards alternative (more circular) practices is a key factor for fit-out circularity. This is a topic that involves different dimensions, including regulation, logistics, finance and behavioural psychology.

• Practical systems that support circular end-of-life pathways are required. The role of regulation in facilitating communication in the supply chain and circularity in material flow should be further studied.
7 References


AFISB (2014). *Fiche de Déclaration Environnementale et Sanitaire [Environmental and Health Declaration Datasheet]*. Évier en grès émaillé de dimensions 120 x 60 cm [120 x 60 cm enamelled stoneware sink].

AFISB (2020). *Fiche de Déclaration Environnementale et Sanitaire [Environmental and Health Declaration Datasheet]*. Lavabo en porcelaine de 50 à 70 cm et sa colonne, sans robinetterie ni vidage [50 x 70 cm porcelain sink and its column, without taps or waste]. Registration number: 2-88:2020


BBP (Better Building Partnership), Dexus and Edge Environment (2015). *Case study in resource recovery from office strip out: Governor Macquarie Tower*. Sidney, Australia.


Chapee (2019). *Profil environnemental Produit [Product Environmental Profile]*. Radiateur à eau chaude statique [Static hot water radiator]. Radiateur à eau chaude statique [Static hot water radiator]. Registration number: CHAP-00002-V01.01-FR


De Dietrich (2019b). Profil environnemental Produit [Product Environmental Profile]. Radiateur à eau chaude statique [Static hot water radiator]. Registration number: DDTH-00004-V01.01-FR


Daloc (2019). Environmental Product Declaration. Wooden door. Registration number: S-P-01392


De Dietrich (2019a). Profil Environnemental Produit [Product Environmental Profile]. Chaudière gaz mixte individuelle murale à condensation [Individual wall-mounted mixed gas condensing boiler]. Registration number: DDTH-00008-V01.01-FR


Herman Miller (2016). Environmental Product Declaration. New Aeron Chair.


Herman Miller (2020). Environmental Product Declaration. Mirra 2 Chair. Registration number: EPD10352


References


Kohler (2014). *Environmental Product Declaration*. Toilet bowl with Pressure Lite flushing technology. Registration number: 4786429138.110.1
References

Kohler (2018). *Environmental Product Declaration*. Comfort height one-piece compact elongated 1.28 gpf toilet with AquaPiston flushing technology and left-hand trip lever. Registration number: 4788111728.151.1

Kohler (2020a). *Environmental Product Declaration*. Undermount single-bowl kitchen sink with accessories and 5 oversized faucet holes. Registration number: 4788111728 181.1

Kohler (2020b). *Environmental Product Declaration*. Floor-mounted rear spud flushometer bowl with exposed trapway. Registration number: 4788111728.170.1


Legrand (2014). *Product Environmental Profile*. Wiremold FloorPort Series Flanged Cover cutout assembly. Registration number: LGRP-00027-V01.01-EN


Ministère du Logement et de l’Habitat Durable [French Ministry of Sustainable Housing] (2016b). Fiche de Déclaration Environnementale et Sanitaire [Environmental and Health Declaration Datasheet]. Ventilo-convecteur (P=1kW) [Cassette fan coil unit (P=1kW)].

Ministère du Logement et de l’Habitat Durable [French Ministry of Sustainable Housing] (2018). Fiche de Déclaration Environnementale et Sanitaire [Environmental and Health Declaration Datasheet]. Porte intérieure 100% vitrée à battants [100% glass interior hinged door]. Registration number: 8676

Ministère du Logement et de l’Habitat Durable [French Ministry of Sustainable Housing] (2019a). Fiche de Déclaration Environnementale et Sanitaire [Environmental and Health Declaration Datasheet]. Luminaire tube fluorescent (P=18 à 24W) [Fluorescent tube luminaire (P=18 to 24W)]. Registration number: 13826

Ministère du Logement et de l’Habitat Durable [French Ministry of Sustainable Housing] (2019b). Fiche de Déclaration Environnementale et Sanitaire [Environmental and Health Declaration Datasheet]. Encastrés intérieurs non-linéaires pour éclairage tertiaire (P=80W) [Non-linear interior recessed luminaires for office lighting (P=80W)]. Registration number: 13627


Mosa (2011). Environmental Product Declaration. EPD Wall Tiles.


References


References


TCS (The Concrete Society) (2013). *Construction and demolition waste recycling may be the key to recovery* [online]. Retrieved from: https://www.sheehancontractors.co.uk/includes/This%20is%20concrete%20article.pdf [Accessed 17 March 2016].


Uniclima (2018). *Profil Environnemental Produit Collectif [Collective Product Environmental Profile]*. Chaudière à condensation gaz individuelle mixte [Individual mixed gas condensing boiler]. Registration number: UNIC-00021-V02.01-FR


Zumbotel (2010). Environmental Product Declaration. AERO2 48W/65 LED 2/28W EVG WH ASQ100. Registration number: EPD-ZG-2010-0001
Appendices

A Published works

A.1 Paper I

Towards more circular office fit-outs: a socio-technical descriptive framework of office fit-out processes

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Keywords
Circular economy
Office building fit-outs
Interior refurbishment
Recycling
Material flow analysis (MFA)

Abstract
The built environment is the most resource intensive sector of the economy, accounting for a significant share of the extracted materials and the total waste generated. Within the built environment the most recurrent replacements of building materials and components take place during fit-outs, which are the process of installing interior fittings, fixtures and finishes. These materials and components are frequently replaced in non-domestic buildings. Non-domestic building fit-outs are therefore responsible for a significant consumption of materials and a large source of waste. However, they tend to go unnoticed and unmeasured in the research about sustainable buildings. The present work aims to study this research gap and analyse the potential for fit-outs to become more sustainable. The approach of this project ties in closely to the concept of circular economy, where materials are kept at their most useful state for as long as possible.

This paper provides a socio-technical descriptive framework of fit-out processes in office buildings. This descriptive framework contains a qualitative analysis of the roles and interactions of involved stakeholders regarding the material flow (based on interviews), and a quantitative material flow analysis (MFA) throughout the downstream supply chain (based on a fit-out case study). The mixed methodology used includes on-site observations, cross-examination of the corresponding design specifications or waste reports, and semi-structured interviews with the involved stakeholders.

The aim of this research is to provide a grounded perspective that allows the identification of process and design improvements that support the transition towards more “circular” fit-outs. It is concluded that there are potential areas of improvement as fit-out practices show a predominantly linear tendency both for decision making and material flows.

Introduction
The built environment is the most resource intensive sector of the economy, accounting annually in the European Union for 50% of all extracted materials, 35% of carbon emissions (European Commission, 2011), and 32% of total waste generated, approximately 830 million tonnes (EEA, 2012). Within the built environment the most recurrent replacements of building materials and components take place during fit-outs, which are defined as the process of installing floor, wall and window coverings, partitions, doors, furniture, equipment, and sometimes mechanical and electrical services (Cole and Kernan, 1996; Forsythe, 2010). In offices, these components can be replaced every 3-10 years (Trucker and Treloar, 1994; Roussac et al., 2008; Forsythe and Wilkinson, 2014). In addition, an outgoing tenant may remove the fit-out (de-fit) and the new tenant will reinstall all these fittings, fixtures, and finishes (re-fit). Accordingly, fit-outs account for a significant amount of wasted resources, and associated embodied carbon emissions throughout the lifecycle of a building.

Office building fit-outs tend to go unnoticed and unmeasured in the debate about sustainable buildings (Forsythe and Wilkinson, 2014) but this is beginning to change. Building fit-out certification methods, such as SRA Rating, BREEAM or LEED exist, but have a low uptake and do not fully cover the circular economy concept. Growing environmental concerns and the gradual increase of UK’s landfill tax (Seely, 2009) certainly encourages stakeholders to pursue waste recycling instead of landfills. However, most fit-out waste gets downcycled, since the original materials or components are generally not designed with recycling or reusing in mind (McDonough and Braungart, 1994).

In order to identify key areas of improvement in the fit-out process and in the use and management of resources, it is pertinent to understand key materials used and waste generated, as well as the destinations of waste streams.
This paper analyses fit-out projects within UCL and London, tracing outgoing waste streams and incoming building materials and components. The roles and responsibilities of different stakeholders within the supply chain are analysed in order to assess which actors have the highest impact on components specification and waste management.

The objective of this work is to set out a socio-technical descriptive framework of office fit-outs from a material flow perspective. The aim being to identify potential improvements in the fit-out process and the design of building components, reflecting on the possible benefits for main stakeholders involved and for society as a whole.

**Background**

**Circular economy**

The environmental consequences of using the biosphere to dispose of waste are becoming critical, such as climate change, loss of biodiversity and natural capital, land degradation, and air and ocean pollution. So the circular economy is a model proposed to replace the current 'take-make-dispose' attitude and to decouple environmental pressures from economic growth. The four sources of value creation in a circular economy to achieve this decoupling are (EMF, 2013): 1) Minimising material use over a product's lifespan. 2) Maximising the number of consecutive use cycles. 3) Diversifying reuse across the value chain and across industries. 4) Using higher quality input materials.

**Non-domestic building fit-outs**

There is large potential to integrate circular economy characteristics in building fit-outs processes. Buildings can be seen and analysed in different layers, depending on function and replacement rate. Brand (1994) proposes six different layers: Site, Structure, Skin, Services, Space plan and Stuff. These layers have increasing rates of replacement, from the Site being permanent to the Space plan and Stuff being replaced every three years or so. Fit-outs relate to the most frequently replaced layers: Services (sometimes), Space plan and Stuff. Brand (1994) demonstrates that in a 50-year cycle, the changes within a building cost three times more than the original building. Multiple authors state that, the embodied energy of fit-outs eventually outweighs that used to construct the building (Cole and Kerman, 1996; Zabalza et al, 2009).

Non-domestic buildings, represent 26% of the total EU building stock floor area, where 6% of the total are offices and 4% education buildings (Economides, 2011). Non-domestic buildings may have 30 to 40 fit-outs during their lifecycle, accounting for an estimated 11% of UK construction spending (RICS, 2016).

The Construction Resources and Waste Platform (2009) carried out a study based on fit-out waste data contained in the SMARTWaste tool. Based on four UK office fit-out projects, the average rate of waste generation is reported to be 6.4 t per 100 m² of gross internal floor area (GFA).

The Better Building Partnership et al. (2015) used a fit-out case study in Sydney, Australia to record the types and amounts of waste generated. A rate of waste generation of close to 10t per 100m² of GFA was found, and 63% of this waste was diverted from landfill. The materials that were not able to be recycled were ceiling and carpet tiles, timbers, office furniture, and paint.

The Institute for Sustainable Futures (2014) performed a series of interviews in Sydney to identify the main waste contributors during fit-outs. The same few materials were consistently nominated: plasterboard, ceiling tiles, carpet, packaging, office furniture (particularly workstations) and the resultant MDF (medium-density fibepboard) and particleboard. It is stated that although some issues can be solved systematically, each material stream needs to be tackled specifically.

Hardie et al. (2011) interviewed twenty-three experts in commercial refurbishments in Sydney to find out the average rate of reuse and recycling. They report that building materials and components such as aluminium, structural steel, steel reinforcing bars, bricks, and concrete, are subject to a high level of recycling, however, little recovery is made from the removal of most internal fittings and finishes during the fit-out process.

**Methodology**

A mixed methodology approach is taken composed of specific methods to answer specific research questions. All research outcomes are then concatenated to provide a socio-technical descriptive framework of the building fit-out process and its material flow.

1) In order to map out the stakeholders within the fit-out supply chain who determine the specification of building components and the management of waste, exploratory interviews were conducted using chain-referral (snowball) sampling. Twelve people related to the fit-out industry were contacted and interviewed. The interview data was cross-checked to lead to an objective interpretation.

2) To describe the function of actors at each stage in the fit-out process and to define the relationships among them (evaluating their impact on the material flow), semi-structured interviews and/or questionnaires were carried out with the stakeholders identified in research objective 1. Three further fit-out experts were interviewed. The key aims in the interviews and questionnaires were to describe the fit-out process in-depth, to identify the roles and interactions of the supply chain actors for each stage, and to define the main drivers and barriers to improved circularity in the fit-out process. The data from interviews and questionnaires was qualitatively analysed to lead to an objective conclusion.

3) In order to define how material flow occurs in fit-out projects, from incoming components to outgoing waste streams, four waste contractors and three managers at recycling facilities were contacted and interviewed. Also,
an office building fit-out was selected as a case study to carry out a material flow analysis of the waste streams generated during the project. Material flow analysis was performed using data from stakeholders’ reports, such as fit-out specifications, site waste management plans (SWMPs) and Recycling Reports. Also, site observations were carried out during and after fit-out.

Fit-out descriptive framework

Fit-out supply chain structure

Several stakeholders within the fit-out supply chain were interviewed including policy makers and stakeholders collaborating in the design team, as well as fit-out contractors, waste contractors and employees in recycling facilities.

From these interviews, it can be concluded that fit-out processes in the area of study are very similar to each other. Thus, a generic fit-out process is considered and described next.

The Client chooses whether to pursue a sustainable fit-out or not and whether to use an assessment method as guideline. The Client also hires the Design Team. The Design Team is usually comprised of an Architect, Project Manager(s), M&E (Mechanical and Electrical) Engineer(s), Quantity Surveyor(s), and sometimes includes a Sustainability Consultant. The Design Team potentially has the highest impact on the decision making within the project, covering decisions such as the specification of building materials and components and the management of waste.

Once the project brief is developed by the Design Team (including project specifications, times and budget), the Project Manager sends out an invitation to tender. Any Fit-out Contractor can then submit a tender, i.e. offer their services to carry out the fit-out works, stating how they would perform the job and how much it would cost. The Fit-out (Re-fit) Contractor who gets the job will be in charge of all the on-site process and they may sub-contract other actors, such as Strip-out (De-fit) Contractor or Waste Contractor. Likewise, the main Fit-out Contractor normally has within their team another Project Manager, M&E Engineer, Quantity Surveyor and a Sustainability Manager.

The assigned Waste Contractor will be in charge of collecting the waste arising from the de-fit and re-fit stages to then take the waste to a transfer site, where it usually gets sorted into different waste streams.

The different waste streams are then sent out to different material recovery facilities (MRFs) or Waste Collectors where they deal with thousands of tonnes of one or several waste streams. The respective Waste Collectors further sort and grade the waste streams for onward delivery, potentially to their respective Final Destinations. These destinations may include recycling within the original industry (closed-loop) or in another industry (cascade), as well as incineration for energy recovery or landfill.

Figure 1 shows the generic structure of the fit-out process. The decision flow is represented in the diagram with a vertical descending orange arrow and the material flow is represented with a horizontal green arrow. It can be appreciated that both the decision and the material flows have a linear tendency.

The Suppliers produce and market the building products, and the Design Team selects from the available offer. The De-fit and Re-fit contractors install and remove the
products, respectively. The Waste Contractor collects the waste and sorts it, to then hand over the different waste streams to the corresponding Waste Intermediaries who further sort and grade the waste before sending it to the respective Final Destinations.

During this study, it was found that the Design Team and the Fit-out Contractor(s) generally have negligible knowledge about the Final Destinations of components and materials, whereas the Waste Contractors and the people in charge of the Final Destinations generally have negligible influence on the specification of these components. It can be suggested that the linear tendency of the decision flow is a barrier for the circularity of the material flow, or in other words, a linear decision flow leads to a linear material flow. However, more analysis and case studies are required to support this supposition.

Fit-out materials and components

Table 1 presents a list of the common fit-out materials and components along with the corresponding European Waste Code (EWC), where available. These materials and components are consistently considered in the literature review and in fit-out SWMPs.

<table>
<thead>
<tr>
<th>Element</th>
<th>EWC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asbestos</td>
<td>17 06 05</td>
</tr>
<tr>
<td>Fines (soil)</td>
<td>17 05 04</td>
</tr>
<tr>
<td>Glass</td>
<td>17 02 02</td>
</tr>
<tr>
<td>Gypsum (incl. plasterboard)</td>
<td>17 08 02</td>
</tr>
<tr>
<td>Hardcore</td>
<td>17 03 07</td>
</tr>
<tr>
<td>Metals-ferrous</td>
<td>17 04 05</td>
</tr>
<tr>
<td>Metals-non-ferrous</td>
<td>17 04 01*</td>
</tr>
<tr>
<td>Mixed waste</td>
<td>17 09 04</td>
</tr>
<tr>
<td>Paint, adhesive, etc.</td>
<td>20 01 07</td>
</tr>
<tr>
<td>Paper &amp; Cardboard</td>
<td>20 01 11</td>
</tr>
<tr>
<td>Plastics (including packaging)</td>
<td>17 02 03</td>
</tr>
<tr>
<td>Textiles</td>
<td>20 03 10</td>
</tr>
<tr>
<td>WEEE</td>
<td>20 03 36</td>
</tr>
<tr>
<td>Wood (including fibreboard)</td>
<td>17 02 01</td>
</tr>
</tbody>
</table>

| Component | N/A
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Batteries</td>
<td>20 01 03</td>
</tr>
<tr>
<td>Carpet</td>
<td>N/A</td>
</tr>
<tr>
<td>Electrical socket</td>
<td>N/A</td>
</tr>
<tr>
<td>Fire alarm</td>
<td>N/A</td>
</tr>
<tr>
<td>Fire extinguisher</td>
<td>N/A</td>
</tr>
<tr>
<td>Insulation</td>
<td>17 06 04</td>
</tr>
<tr>
<td>Light fluorescent tubes</td>
<td>20 01 23</td>
</tr>
<tr>
<td>Light-Other</td>
<td>N/A</td>
</tr>
<tr>
<td>Office furniture</td>
<td>N/A</td>
</tr>
<tr>
<td>Raised access floor tiles</td>
<td>N/A</td>
</tr>
<tr>
<td>Suspended ceiling tiles</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Table 1: Common fit-out materials and components (Author generated, 2017).

Fit-out waste generation

A major waste contractor in London was contacted in order to find out the top material streams or waste streams generated during fit-out projects (Table 2). Over 90% of the waste they collect comes from building fit-outs. Figure 2 shows the share or percentage (by weight) for each material stream relative to the overall waste collection, for the first quarter of 2017.

Material flow in an office fit-out case study

The fit-out took place in London during 2016, and is considered a best-practice fit-out in the UK. The fit-out gross internal floor area (GFA) is 162m² and the project value is £60k.

The information presented here was provided (and cross-checked) by the design team, the fit-out contractor and the waste contractor.

Outgoing waste

The total waste generated (considering de-fit and re-fit) is 3.81t, with a landfill diversion rate of 99.5%. The rate of waste generation is 2.33t per 100m² of GFA, which is 63% lower than UK average (6.4t / 100m² GFA).

Table 3 shows a breakdown of the waste streams generated during the de-fit stage. The waste during this stage (2.82t) accounts for 74% of the total waste generated.

Table 4 shows the waste stream breakdown for the re-fit stage, which accounts for only 26% of the total waste.

Table 5 presents waste stream breakdown combined for both the de-fit and re-fit stages. For this case study, gypsum (including plasterboard) accounts for the largest share (34.0%), followed by mixed waste (31.9%), wood (17.0%), office furniture (9.9%), and insulation (9.2%).

![Figure 2: Share (by weight) for each material stream relative to the overall waste collection, for the first quarter of 2017 (Waste Contractor’s report, 2017).](image)
Appendices

![Table 3. Waste generated during de-fit (fit-out SWAP, 2010).](image)

<table>
<thead>
<tr>
<th>Element</th>
<th>Weight [t]</th>
<th>Recycled [t]</th>
<th>Disposed [t]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gypsum</td>
<td>0.96</td>
<td>0.96</td>
<td>0.00</td>
</tr>
<tr>
<td>Mixed waste</td>
<td>0.90</td>
<td>0.88</td>
<td>0.02</td>
</tr>
<tr>
<td>Wood</td>
<td>0.48</td>
<td>0.48</td>
<td>0.00</td>
</tr>
<tr>
<td>Office furniture</td>
<td>0.28</td>
<td>0.28</td>
<td>0.00</td>
</tr>
<tr>
<td>Insulation</td>
<td>0.20</td>
<td>0.20</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>Total [t]</strong></td>
<td><strong>2.82</strong></td>
<td><strong>2.80</strong></td>
<td><strong>0.02</strong></td>
</tr>
<tr>
<td><strong>Percentage [%]</strong></td>
<td><strong>100</strong></td>
<td><strong>99.3</strong></td>
<td><strong>0.7</strong></td>
</tr>
</tbody>
</table>

Table 3. Waste generated during de-fit (fit-out SWAP, 2010).

![Table 4. Waste generated during re-fit (fit-out SWAP, 2010).](image)

<table>
<thead>
<tr>
<th>Element</th>
<th>Weight [t]</th>
<th>Recycled [t]</th>
<th>Disposed [t]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gypsum</td>
<td>0.72</td>
<td>0.72</td>
<td>0.00</td>
</tr>
<tr>
<td>Mixed waste</td>
<td>0.27</td>
<td>0.26</td>
<td>0.01</td>
</tr>
<tr>
<td><strong>Total [t]</strong></td>
<td><strong>0.99</strong></td>
<td><strong>0.98</strong></td>
<td><strong>0.01</strong></td>
</tr>
<tr>
<td><strong>Percentage [%]</strong></td>
<td><strong>100</strong></td>
<td><strong>99.0</strong></td>
<td><strong>1.0</strong></td>
</tr>
</tbody>
</table>

Table 4. Waste generated during re-fit (fit-out SWAP, 2010).

![Table 5. Waste generated during de-fit and re-fit (fit-out SWAP, 2010).](image)

<table>
<thead>
<tr>
<th>Element</th>
<th>Weight [t]</th>
<th>Recycled [t]</th>
<th>Disposed [t]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gypsum</td>
<td>1.68</td>
<td>1.68</td>
<td>0.00</td>
</tr>
<tr>
<td>Mixed waste</td>
<td>1.17</td>
<td>1.15</td>
<td>0.02</td>
</tr>
<tr>
<td>Wood</td>
<td>0.48</td>
<td>0.48</td>
<td>0.00</td>
</tr>
<tr>
<td>Office furniture</td>
<td>0.28</td>
<td>0.28</td>
<td>0.00</td>
</tr>
<tr>
<td>Insulation</td>
<td>0.20</td>
<td>0.20</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>Total [t]</strong></td>
<td><strong>3.81</strong></td>
<td><strong>3.79</strong></td>
<td><strong>0.02</strong></td>
</tr>
<tr>
<td><strong>Percentage [%]</strong></td>
<td><strong>100</strong></td>
<td><strong>99.5</strong></td>
<td><strong>0.5</strong></td>
</tr>
</tbody>
</table>

Table 5. Waste generated during de-fit and re-fit (fit-out SWAP, 2010).

Waste stream final destinations

The Fit-out Contractor (and the upstream stakeholders) tend to sub-contract a Waste Contractor that can ensure a high rate of landfill diversion. This is generally driven by environmental reasons whether or not a certification assessment is followed.

Another important reason for landfill diversion is the gradual increase of landfill tax, as handing the waste to a Waste Contractor is normally cheaper than landfilling. The ‘gate fee’ refers to the price that the Waste Contractor charges per tonne for each waste stream. The gate fee for Mixed waste is generally the highest, so it is advisable for the Fit-out Contractor to segregate waste on-site. In fact, some segregated waste streams are collected free of charge or even paid for (negative gate fee), as is the case for segregated Metals, Plastics, and Paper & Cardboard.

Figure 3 shows the generally linear waste stream among the downstream stakeholders for the office fit-out case study. Note that 15% of gypsum is closed-loop recycled. Although 99% of the waste was diverted from landfill, all material streams diversify into multiple Final Destinations that require a lower grade of material quality.

In this case, Wood is sent to Belgium, mixed Metals generally end up in Spain or Turkey (or other countries depending on the offered price), and Plastics are sent to China. All other Final Destinations are located within the UK.

![Figure 3. Waste streams flow in tonnes for an office building fit-out.](image)
Conclusions

Given the emerging socio-technical descriptive framework of office fit-outs, it is clear there are several areas that can be improved.

It is found that the office (and non-domestic) fit-out supply chain has a generic structure in which both the decision and material flows have a predominantly linear tendency. The stakeholders in the supply chain with the highest impact on the specification of materials and components and the decisions on waste management are generally the client and the design team.

Currently, good-practice fit-out projects (and the corresponding assessment methods) pursue high recycling percentages for the generated waste streams. However, this study found that the stakeholders in the supply chain are generally unaware of the waste streams’ final destinations, i.e., what different waste streams get recycled into or used for.

In order to be able to design more “circular” fit-outs, the stakeholders involved in the supply chain should have more effective communication. That is to say, the suppliers and the design team should understand what happens with materials and components at the end-of-life. Accordingly, the actors in charge of the final destinations of these components and materials should provide a systematic feedback to the suppliers and the design team.

In the office fit-out case study, it is found that the rate of waste generation was 2.35 tonnes per 100m² of gross internal floor area (GFA), which is lower than the UK reported average of 6.4. However, the fit-out project analysed in this paper is considered best-practice. On the other hand, the top waste generated during this case study were gypsum, mixed waste, and wood, which coincides with the data provided by the interviewed waste contractor.

Further studies on building fit-outs are required in order to confirm the findings presented here, and further investigate the share and final destinations of each waste stream. Likewise, it would be useful to carry out a Life-Cycle Analysis (LCA) for the building components most commonly found in fit-out projects.

Acknowledgments

The authors acknowledge the support and the data provided by the interviewees and the corresponding stakeholders.

References

BBP (Better Building Partnership), Dexus and Edge Environment (2013). Case study to resource recovery from office strip out: Governor Macquarie Tower, Australia.


A.2 Paper II
Material and decision flows in non-domestic building fit-outs

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ABSTRACT
The built environment is the most resource intensive sector of the economy, accounting for a significant share of the extracted materials and the total waste generated. Within the built environment the most recurrent replacements of building materials and components take place during fit-outs, which are the process of installing interior fittings, fixtures and finishes. These materials and components are frequently replaced in non-domestic buildings.

Non-domestic building fit-outs are therefore responsible for a significant consumption of materials and a large source of waste. However, they tend to be excluded and unmeasured in the research on the built environment. The present work aims to study this research gap and analyse the potential for fit-outs to become more sustainable. The approach of this project lies in closely to the concept of circular economy, where materials are kept at their most useful state for as long as possible.

This paper analyses fit-out practices within London, identifying the supply-chain stakeholders, the key materials used and the waste streams generated, while tracing the decision and material flows across the supply chain. A material flow analysis (MFA) is conducted for a fit-out case study, showing the paths and destinations of the waste generated. The mixed methodology includes on-site observations, cross-examination of the corresponding waste reports, MFA, and qualitative analysis of interviews with the involved stakeholders.

The aim of this research is to provide a grounded perspective that allows the identification of process and design flaws as well as potential improvements that support the transition towards more "circular" fit-outs. It is concluded that there are potential areas of improvement as fit-out practices show a predominantly linear tendency both for decision making and material flows, in which there is a discontinuity of communication and material-flow information across the supply chain.

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1. Introduction
The built environment is the most resource intensive sector of the economy, accounting annually in the European Union for 50% of all extracted materials, 35% of carbon emissions (European Commission, 2011), and 32% of total waste generated, approximately 830 million tonnes (JEA, 2012). Within the built environment the most recurrent replacements of building materials and components take place during fit-outs, which are defined as the process of installing floor, wall and window coverings, partitions, doors, furniture, equipment, and sometimes mechanical and electrical services (Coile and Reman, 1996; Forsythe, 2010). In non-domestic buildings these components can be replaced every 3–10 years (Truckor and Treloar, 1994; Roussac et al., 2008; Forsythe and Wilkinson, 2014). In addition, an outgoing tenant may remove the fit-out (de-fit) and the new tenant will reinstall all these fittings, fixtures, and finishes (re-fit). Accordingly, fit-outs account for a significant amount of wasted resources, and associated embodied carbon emissions throughout the lifecycle of a building.

Building fit-outs trend to go unnoticed and unmeasured in the debate about sustainable buildings (Forsythe and Wilkinson, 2014) but this is beginning to change. Building fit-out certification methods, such as BREEAM (BRE, 2008c) or LEED (USGBC, 2018b) exist, but have a low uptake (ECORYS, 2014) and do not fully cover the circular economy concept. Growing environmental concerns and the gradual increase of UK’s landfill tax (Seely, 2009) certainly encourages stakeholders to pursue waste recycling instead of landfilling. However, most fit-out waste gets downsized, since the original materials or components are generally not designed with recycling or reusing in mind (McDonough and Braungart, 2002).

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9595-6526/2018 Elsevier Ltd. All rights reserved.
In order to identify key areas of improvement in the fit-out process and in the use and management of resources, it is pertinent to understand the key materials used and waste generated, as well as the destinations of waste streams.

This paper analyses non-domestic fit-out practices within University College London (UCL) and London, identifying the supply-chain stakeholders, the main materials used and waste streams generated, while tracing the decision and material flows across the supply chain. The objective of this work is to set a framework of characteristics of non-domestic building fit-outs and providing a more detailed explanation of a higher education institution (HEI) building fit-out, from a material flow perspective. The aim being to identify potential improvements in the fit-out process and the design of building components, reflecting on the possible benefits for main stakeholders involved and for society as a whole.

The following sections include the “Background” and the “Methodology”, following on to present a “Common fit-out framework”, in which secondary data obtained through interviews is used to present common characteristics of non-domestic fit-outs in the area. Next, a “HEI building fit-out case study” is closely analysed to show more specific attributes of a fit-out procedure, including a material flow analysis (MFA). Finally, findings are discussed and the paper concludes in the “Discussion and conclusions” section.

1.2 Background

Building fit-outs are a type of refurbishment, and the latter is defined as any building work that modifies the interior or exterior structure or aesthetic appearance of a building (RICS, 1997), normally with the aim to increase its social or economical value (RICS, 1997). In this context, the term refurbishment and renovation are interchangeable (RICE, 1987) and cycle through modifications to the building such as retrofits (adding something to improve the building’s performance (DHW, 2018)) and fit-outs (which relate to interior modifications).

Buildings can be seen and analysed in different layers, depending on function and value. The top layer is the ‘site’ (geographical setting), a ‘structure’ (load-bearing elements), ‘skin’ (building envelope), ‘services’ (fabric pipes, partitions, ceiling, floor), and ‘staff’ (furniture and equipment). These layers have increasing rates of replacement, with the site being permanent to the space plan and staff being replaced every three years or so. Fit-outs relate to the most frequently replaced layers: services (sometimes), space plan and staff. Brand (1994) demonstrates that in a 50-year cycle, the changes within a building cost three times more than the original building. Multiple authors state that the embodied energy of fit-outs eventually outweighs that used to construct the building (Cole and Keman, 1996; Zabalza et al., 2009).

Non-domestic buildings, representing 26% of the total EU building stock per floor area, where 6% of the total are offices and 45% education buildings (Economist, 2011). Non-domestic buildings may have 30 to 40 fit-outs during their lifecycle, accounting for an estimated 11% of UK construction spending (RICS, 2018). The Construction Resources and Waste Platform (2009) carried out a study based on fit-out waste data contained in the Smart-Waste (RIS, 2018) tool. The average rate of waste generation is reported to be 0.44 per 100 m² of gross internal floor area (GIFA) for offices (based on four UK office fit-out projects), 10.3 kg per 100 m² of GIFA for retail (based on six projects), and 0.10 kg per 100 m² of GIFA for education institution buildings (based on two projects). The reasons for the variability among types of space are not discussed.

The Better Building Partnership (2015) used a fit-out case study in Sydney, Australia to record the types and amounts of waste generated. A rate of waste generation of close to 10 kg per 100 m² of GFA was found, and 63% of this waste was diverted from landfill. The materials that were not able to be recycled were ceiling and carpet tiles,timbers, office furniture, and paper.

The Institute for Sustainable Futures (2014) performed a series of interviews in Sydney to identify the main waste contributors during fit-outs. The same few materials were consistently nominated: plasterboard, ceiling tiles, carpentry, packaging, office furniture (particularly workstations) and the resultant MEW (medium-density fibreglass) and particleboard. It is stated that although some issues can be solved systematically, each material stream needs to be tackled specifically.

Hardie et al. (2011) interviewed twenty-three experts in commercial refurbishments in Sydney to find out the average rate of re-use and recycling. They report that building materials and components such as aluminium, structural steel, steel reinforcing bars, bricks, and concrete, are subject to a high level of recycling, however, little recovery is made from the removal of most internal fittings and finishes during the fit-out process. The findings of the present work were partly presented in a conference paper at PLATE 2017, in which a similar fit-out case study to the one included in this paper was used to carry out a material flow analysis (MFA), aiming to tie the fit-out process with the concept of circular economy (Casas-Arredondo et al., 2017). Non-domestic building fit-outs generally represent the most recurrent refurbishment in the built environment and thus present an important opportunity to apply the principles of circular economy. The circular economy is a model proposed to replace the current ‘take-make-dispose’ scheme and to decouple environmental pressures from economic growth. The four sources of value creation in a circular economy to achieve this decoupling are (EMP: 2013): 1) minimising material use over a product’s lifespan; 2) maximising the number of consecutive cycles; 3) diversifying reuse across the value chain and across industries; and 4) using higher quality input materials. The term “circularity” is used in this work to reflect to what extent building materials or components keep their functional value either by being retained (in-situ), reused (on-site or off-site) or closed loop recycled.

There are current organisations or companies that support the transition towards more circular building fit-outs, acting as a sort of reuse intermediaries. Redistribution networks, such as Globalchain (2018), Materia (2018), Materia (2018), and ReUse (2018) allow potential “re-users” to find reclaimed building components in order to reuse them in building projects.

2. Methodology

A mixed methodology approach is taken composed of specific methods to answer specific research questions. The research output contains a common framework of the non-domestic building fit-out process and an explanation of a HEI building fit-out case study, from a material flow perspective. Fig. 1 shows a graphical representation of the methodological procedure. The research tasks were divided into three categories, as follows:

1) Mapping out the stakeholders within the fit-out supply chain who determine the specification of building components and the management of waste: exploratory interviews were conducted using chain-referral (snowball) sampling. Twelve people related to the fit-out industry were contacted and interviewed. The interview data was cross-checked to lead to an objective interpretation.

2) Describing the function of actors at each stage in the fit-out process and defining the relationships among them
(evaluating their impact on the material flow); semi-structured interviews were carried out with the stakeholders identified in research objective 1. Three further fit-out experts were interviewed. The key aims in the interviews were to describe the fit-out process in-depth, to identify the roles and interactions of the supply-chain actors for each stage, and to define the main drivers and barriers to improved circularity in the fit-out process. The data from interviews and questionnaires was qualitatively analysed using NVivo.

3) Identifying the key material flows in fit-out projects: a) two Waste Contractors were interviewed and seven material recovery facilities (MRFs) were contacted. Also, b) a HEI building fit-out was selected as a case study to carry out a material flow analysis (MFA) of the waste streams generated during the project. The MFA was performed using data from stakeholders’ reports, such as fit-out specifications, site waste management plans (SWMPs) and recycling reports. Also, site observations were carried out during and after fit-out. Lastly, c) a Sankey diagram was constructed for the case-study MFA using SankeyMATIC.

3. Common fit-out framework

3.1. Common fit-out supply chain structure

Several stakeholders within the non-domestic fit-out supply chain were interviewed including policy makers and stakeholders collaborating in the design team, as well as Fit-out Contractors, Waste Contractors and MRFs. From these interviews, it was concluded that fit-out processes encountered in the area of study are very similar to each other. Therefore, a common office and HEI fit-out supply chain is determined and described next.

Fig. 2 shows the generic structure of the fit-out supply chain. The decision flow is represented in the diagram with an orange
arrow and the material flow is represented with a green arrow. It can be appreciated that both the decision and the material flows have a linear tendency.

The fit-out supply chain is generally formed in the following way: the client decides to undertake a fit-out, then choses the boundaries. They need to decide whether sustainability is a key requirement and what level is required, as well as whether to use an assessment method as guideline. The client also hires the Design Team, which is usually comprised of an Architect, Project Manager(s), M&E (Mechanical and Electrical) Engineer(s), Quantity Surveyor(s), and sometimes includes a Sustainability Consultant. The Design Team potentially has the highest impact on the decision making within the project, creating decisions such as the specification of building materials and components and the management of waste.

Once the project brief is developed by the Design Team (including project specifications, times and budget), the Project Manager sends out an invitation to tender. The invitation to tender (also known as Request for Tender) is commonly sent to prospective contractors (Select Tender), but can also take the form of an Open Tender which is done by public advertisement. Any fit-out Contractor can then submit a tender, i.e. offer their services to carry out the fit-out works, stating how they would perform the job and how much it would cost. The tendering process should not be biased so the offer that best meets the requirements outlined in the Tender Package and provides the best value for money should get the contract. The fit-out Contractor who gets the job, known thereafter as the General Contractor, will be in charge of all the on-site processes and may sub-contract other actors, such as a Strip-out Contractor (also known as Demolition Contractor) or a Waste Contractor. Likewise, the General Contractor normally has within their team an Internal Project Manager, M&E Engineer, Quantity Surveyor and a Sustainability Manager.

The Waste Contractor assigned by the General Contractor will be in charge of collecting the waste arising from the de-fit (demolition) and re-fit (installation) stages to then take it to a transfer site, where waste usually gets sorted into different waste streams. In some instances, the Strip-out Contractor may assign a different Waste Contractor for the de-fit process, or the Strip-out Contractor may take care of the waste themselves if they have a waste-carrier licence.

The different waste streams are then sent out to different ones or Waste dealers where each waste stream is aggregated. Each MRF may deal with one or several different waste streams. The respective Waste dealers further sort and grade the waste streams for onward delivery, potentially to their respective final destinations. These destinations may include recycling within the original industry (closed-loop) or in another industry, as well as incineration for energy recovery or landfill.

In terms of material flow, the Suppliers produce and market the building products, and the Design Team selects from the available offer. The General and Strip-out contractors install and remove the products, respectively. The Waste Contractor collects the waste and sorts it, then hand over the different waste streams to the corresponding Waste dealers who further sort and grade the waste before sending it to the respective final destinations.

During this study, it was found that the Design Team and the General/Strip-out Contractor generally have negligible knowledge about the final destinations of components and materials, whereas the Waste Contractors and the people in charge of the final destinations generally have significant influence on the specification of these components. It can be suggested that the linear tendency of the decision flow is a barrier for the circularity of the material flow.

3.2. Common fit-out materials and components

| Tables 1 and 2 present a list of the common fit-out materials and components, respectively, along with the corresponding European Waste Code (EWC), where available. These materials and components are consistently considered in the literature review and in fit-out SWMPs. The components shown in Table 2 are manufactured products composed of more than one material.

Out of these materials and components, there are some deemed as hazardous waste (asbestos, paint and adhesives, fluorescent lamps, WEEE), while hardcore is considered to be inert and entails a lower landfill tax. Gypsum-based products are required to be closed-loop recycled or landfilled in a separate cell away from biodegradable waste to avoid the production of hydrogen sulphide (UK Government, 2018).

A waste stream as it is composed of various materials and components, but it is included in Table 1 in order to be comprehensive.

3.3. Common fit-out waste generation

Building fit-out materials and components are generally considered to be waste, and treated as such, once they are removed from the building site. The umbrella of building materials and components are categorised into a few waste streams in order to be segregated and treated. A major Waste Contractor in London was contacted in order to find out the top waste streams generated during fit-out projects (Table 3). Over 90% of the waste they collect comes from building fit-outs. Fig. 2 shows the share or percentage (by weight) for each material stream relative to the overall waste collection, for the first quarter of 2017. Gypsum (including plasterboard) accounts for the largest share, followed by mixed waste, metals, woods (including fiberglass and particleboard), glues, hardcore, paper & cardboard, WEEE, and fluorescent lamps.

4. HE3 building fit-out case study

Four non-domestic building fit-outs were analysed during this work in order to quantify the material flow during the fit-out process. A higher education institution (HEI) building fit-out was selected as case study and is presented below. The fit-out project aimed to turn formerly unused space into multi-use space for the teaching of Chinese language and culture, as part of the UCL Institute of Education. The Confucius Institute fit-out took place between December 2016 and June 2017, with a project value of £666k, and was certified as SCA Gold using the Office Scheme. The 1847 building is located in Bloomsbury and belongs to UCL Estates. The building comprises four stories plus a basement, which result in a gross floor area (GFA) of 290 m².

The information presented in this section was provided [and cross-checked] by the Client’s (UCL) Sustainability Officer (personal interview, 24 November 2016 and 01 May 2017), the General Contractor’s Site Manager (personal interview, 24 November 2016), the Waste Contractor (personal interview, 26 December 2016 and 11 April 2017) and the Waste Contractor’s Senior Sustainability Manager (personal interview, 21 October 2016; personal communication 05 June 2017).

4.1. Case-study supply chain structure

Fig. 3 shows the supply-chain stakeholders and structure. The Client was represented by a UCL Stakeholder, a UCL Project Manager and the UCL Sustainability Officer. The Client assigned a Design Team to be in charge of the whole project design which was compiled in the Tender Package. The Design Team comprised actors...
Table 1
Common fit-out materials (Author generated, 2017).

<table>
<thead>
<tr>
<th>MATERIALS</th>
<th>Element</th>
<th>EWC</th>
<th>Waste stream</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asbestos</td>
<td>17 06 05</td>
<td>asbestos</td>
<td></td>
</tr>
<tr>
<td>Ceramics</td>
<td>17 01 03</td>
<td>hardwood</td>
<td></td>
</tr>
<tr>
<td>Glass</td>
<td>17 02 02</td>
<td>glass</td>
<td></td>
</tr>
<tr>
<td>Gypsum (including plasterboard)</td>
<td>17 08 02</td>
<td>gypsum</td>
<td></td>
</tr>
<tr>
<td>Hardwood</td>
<td>17 01 07</td>
<td>hardwood</td>
<td></td>
</tr>
<tr>
<td>Insulation</td>
<td>17 06 04</td>
<td>varieties</td>
<td></td>
</tr>
<tr>
<td>Metals--ferrous</td>
<td>17 04 05</td>
<td>metals</td>
<td></td>
</tr>
<tr>
<td>Metals--Non-ferrous</td>
<td>17 04 01</td>
<td>metals</td>
<td></td>
</tr>
<tr>
<td>Mixed waste</td>
<td>17 09 04</td>
<td>mixed waste</td>
<td></td>
</tr>
<tr>
<td>Paint, adhesive, etc.</td>
<td>20 01 27</td>
<td>hazardous</td>
<td></td>
</tr>
<tr>
<td>Paper &amp; Cardboard</td>
<td>20 01 01</td>
<td>paper</td>
<td></td>
</tr>
<tr>
<td>Plastics (including packaging)</td>
<td>17 02 03</td>
<td>plastics</td>
<td></td>
</tr>
<tr>
<td>Textiles</td>
<td>20 01 31</td>
<td>textiles</td>
<td>mixed waste</td>
</tr>
<tr>
<td>Wood (including fibreboard)</td>
<td>17 02 01</td>
<td>wood</td>
<td></td>
</tr>
</tbody>
</table>

* Non-ferrous metals also include EWCs 17 04 02, 17 04 03, 17 04 04 and 17 04 06.

Table 2
Common fit-out components (Author generated, 2017).

<table>
<thead>
<tr>
<th>COMPONENTS</th>
<th>Element</th>
<th>EWC</th>
<th>Waste stream</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carpet/carpet tiles</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Doors</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Ductwork</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Electrical socket</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Fluorescent lamps</td>
<td>20 01 21</td>
<td>metal &amp; wood</td>
<td></td>
</tr>
<tr>
<td>Light fittings</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Office furniture</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Raised flooring</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Extractor fans</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Composite ceiling tiles</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>WEEE</td>
<td>20 01 26</td>
<td>WEEE</td>
<td></td>
</tr>
</tbody>
</table>

* Symbols & means AND, | means OR

Table 3
Weight and share for each material stream collected for the first quarter of 2017 (Waste Contractor’s report, 2017).

<table>
<thead>
<tr>
<th>Waste stream</th>
<th>EWC</th>
<th>Weight [t]</th>
<th>Share [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gypsum (including plasterboard)</td>
<td>17 08 02</td>
<td>72.59</td>
<td>31.8</td>
</tr>
<tr>
<td>Mixed waste</td>
<td>17 09 04</td>
<td>68.25</td>
<td>29.0</td>
</tr>
<tr>
<td>Metals</td>
<td>17 04 01</td>
<td>32.84</td>
<td>14.4</td>
</tr>
<tr>
<td>Wood (including fibreboard)</td>
<td>17 02 01</td>
<td>25.06</td>
<td>11.0</td>
</tr>
<tr>
<td>Glass</td>
<td>17 02 02</td>
<td>13.02</td>
<td>5.7</td>
</tr>
<tr>
<td>Hardwood</td>
<td>17 01 07</td>
<td>11.90</td>
<td>5.2</td>
</tr>
<tr>
<td>Paper &amp; Cardboard</td>
<td>20 01 01</td>
<td>6.18</td>
<td>2.7</td>
</tr>
<tr>
<td>WEEE</td>
<td>20 01 36</td>
<td>0.32</td>
<td>0.1</td>
</tr>
<tr>
<td>Fluorescent lamps</td>
<td>20 01 21</td>
<td>0.30</td>
<td>0.1</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>228.46</td>
<td>100.0</td>
</tr>
</tbody>
</table>

* Metals also include EWCs 17 04 02 to 17 04 06.

From different firms respectively: namely, a Project Manager (also known as External Project Manager), an Architect, a M&E Consultant, and a Quantity Surveyor. The Design Team appointed a General Contractor to be in charge of the works on site, and the General Contractor, in turn, appointed a Strip-out Contractor to carry out the de-fit stage. The Suppliers were selected by both the Design Team and the General Contractor, as some building components and materials were specified by the Design Team and the General Contractor changed some of the specified components and added new ones. The Waste Contractor, which was subcontracted by the General Contractor, was used for both the de-fit and re-fit stages. However, the Strip-out Contractor hired a waste carrier in order to deliver the de-fit waste to the Waste Contractor’s transfer site, while the re-fit waste was collected by the Waste Contractor themselves. The Waste Contractors determined different Waste dealers for different waste streams. Finally, the respective final destinations were established by the Waste dealers.

In terms of decision flow among supply-chain stakeholders, it was recognised that the communication mainly took place between...
the adjacent stakeholders (as seen in Fig. 3), but there was no effective communication among non-adjacent actors. When interviewed, the General Contractor’s Site Manager said he was unaware of the potential final destinations of waste streams generated during the fit-out process. The General Contractor’s Environmental and Sustainability Manager (personal interview, 27 September 2016) said at an earlier interview that he had no certainty about what becomes of the fit-out waste but he believed that most waste streams get downcycled.

When the Waste Contractor’s Senior Sustainability Manager was interviewed, a similar response was provided. On the other hand, he said Waste Contractors are commonly not taken into account, in the design stage or for the decision making at the fit-out process, although they could advise and support on issues such as pre-refurbishment audit, potential component reuse, waste segregation, and take-back schemes.

In the same way as the decision flow, the material flow for this case study shows a predominantly linear tendency. Fig. 4 shows the path followed by the material/waste throughout the different locations within the supply chain. Materials and components were firstly provided by suppliers and taken to the building site where they are installed and subsequently removed. When these materials and components got removed, they were considered and treated as waste so they were taken to a waste transfer site to be segregated. After segregation, different waste streams were taken to the corresponding MRFs before being sent to the corresponding final destinations.

4.2. Case-study waste generation

The total waste generated during this fit-out project was 35,287t, including 32,887t for the de-fit stage, with a landfill diversion rate of 75%, and 23,109t for the re-fit stage, where the reported landfill diversion rate was 99%. The average landfill diversion rate considering both stages was 91%, while the rate of waste generation was 12.17t per 100 m² of GFA. Table 4 shows a breakdown of the waste streams generated during the de-fit stage. Waste during this stage accounts for 35% of the total waste generated. Table 5 shows the waste-stream breakdown for the re-fit stage, which accounts for 65% of the total waste. Lastly, Table 6 presents the waste-stream breakdown combined for both the de-fit and re-fit stages.

Fig. 5 presents a bar chart showing the percentages or shares (by weight) of each waste stream relative to the overall waste collection. For this case study, hardcore accounts for the largest share (27%), followed by wood -including fibreboard- (21%), mixed waste (21%), textiles -including carpet tiles- (18%), gypsum -mainly plasterboards- (7%), metals (7%), plastics (5%), glass (4%), and asbestos (1%). It should be noted that building components removed during this fit-out project were considered waste and categorized into the respective waste stream as soon as they were removed, thus decreasing their functional value. However, there are many components in good condition that could have been retained or reused, saving the energy and CO₂ emissions embodied in the new components. When interviewed, the General Contractor’s Site Manager claimed that offsite reuse of components was negligible due to the lack of a market for reused building components. Accordingly, some components were disposed of despite being in good or excellent condition, such as: 218 m² of carpet tiles and the plywood layer underneath, 30 light fittings, 64 fluorescent lamps, 115 wooden shelves, and 70 electrical sockets, among others. These building components were taken by the Waste Contractor in order to be presumably recycled. The next section presents the paths and final destinations of the waste streams generated during the fit-out project.

4.3. Case-study waste stream destinations

The General Contractor (and the upstream stakeholders) tend to sub-contract a Waste Contractor that can ensure a high rate of landfill diversion. This is generally driven by environmental reasons whether or not a certification or assessment method is followed. Another important reason for landfill diversion is the gradual increase of landfill tax, as handing the waste to a Waste Contractor is normally cheaper than landfilling. The ‘gate fee’ in this context refers to the price that the Waste Contractor charges per tonne for each waste stream collected. For this case study, the highest gate fee was charged for mixed waste, followed by plasterboard, and wood. Hardcore was collected free of charge, while other waste streams were even paid for, such as metals, paper & cardboard, and plastics.

Fig. 6 shows the flow of the respective waste streams across the supply chain for the fit-out case study. Each waste stream is represented by a different colour – a change of colour at the end means the waste stream has been converted into something else. Although 91% of the waste was reported as recycled, the final destinations include other recovery alternatives such as composting (0.5t) and incineration (2.2t). Recycled waste streams diversify into multiple recycling destinations that require a lower grade of material quality, with the exception of 60% of the gypsum, which was turned into new plasterboard. Therefore, only 4% (1.5t) of material was closed-loop recycled out of 3928t of waste generated during the fit-out process. Gypsum was the only waste stream that showed some percentage of closed-loop recycling, driven by UK regulations which stipulate a special treatment for gypsum-based products. About 8% (2.7t) of the total waste was landfilled, while asbestos (0.48t) were collected by a specialist contractor and sent to deep landfill burial.

In this case, wood was sent to Belgium, metals ended up in Spain or Turkey (or other countries depending on the offered price at the time), and plastics were sent to China, while all other final destinations are located within the UK. In total, around 41% (14.64t) of waste was exported abroad.
Table 4
Waste generated during de-fit at UCL Confinia Institute (fit-out SWMP, 2017).

<table>
<thead>
<tr>
<th>Item</th>
<th>Weight [t]</th>
<th>Recycled [t]</th>
<th>Disposed [t]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asbestos</td>
<td>0.49</td>
<td>0.00</td>
<td>0.49</td>
</tr>
<tr>
<td>Glass</td>
<td>0.37</td>
<td>0.37</td>
<td>0.00</td>
</tr>
<tr>
<td>Hazard</td>
<td>4.00</td>
<td>4.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Mixed waste</td>
<td>7.32</td>
<td>4.76</td>
<td>2.56</td>
</tr>
<tr>
<td>Total [t]</td>
<td>12.58</td>
<td>9.13</td>
<td>3.45</td>
</tr>
<tr>
<td>Percentage [%]</td>
<td>100</td>
<td>73.8</td>
<td>26.2</td>
</tr>
</tbody>
</table>

Table 5
Waste generated during re-fit at UCL Confinia Institute (fit-out SWMP, 2017).

<table>
<thead>
<tr>
<th>Item</th>
<th>Weight [t]</th>
<th>Recycled [t]</th>
<th>Disposed [t]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hazard</td>
<td>5.47</td>
<td>5.47</td>
<td>0.00</td>
</tr>
<tr>
<td>Glass</td>
<td>1.61</td>
<td>1.61</td>
<td>0.00</td>
</tr>
<tr>
<td>Metals</td>
<td>2.49</td>
<td>2.49</td>
<td>0.00</td>
</tr>
<tr>
<td>Plasterboard</td>
<td>2.50</td>
<td>2.50</td>
<td>0.00</td>
</tr>
<tr>
<td>Plastic</td>
<td>1.61</td>
<td>1.61</td>
<td>0.00</td>
</tr>
<tr>
<td>Textiles</td>
<td>2.05</td>
<td>2.05</td>
<td>0.13</td>
</tr>
<tr>
<td>Wood</td>
<td>7.36</td>
<td>7.36</td>
<td>0.00</td>
</tr>
<tr>
<td>Total [t]</td>
<td>23.10</td>
<td>22.97</td>
<td>0.13</td>
</tr>
<tr>
<td>Percentage [%]</td>
<td>100</td>
<td>91.4</td>
<td>8.6</td>
</tr>
</tbody>
</table>

Table 6
Waste generated during de-fit and re-fit at UCL Confinia Institute (fit-out SWMP, 2017).

<table>
<thead>
<tr>
<th>Item</th>
<th>Weight [t]</th>
<th>Recycled [t]</th>
<th>Disposed [t]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asbestos</td>
<td>0.49</td>
<td>0.00</td>
<td>0.49</td>
</tr>
<tr>
<td>Hazard</td>
<td>9.47</td>
<td>9.47</td>
<td>0.00</td>
</tr>
<tr>
<td>Mixed waste</td>
<td>7.32</td>
<td>4.76</td>
<td>2.56</td>
</tr>
<tr>
<td>Glass</td>
<td>1.39</td>
<td>1.39</td>
<td>0.00</td>
</tr>
<tr>
<td>Metals</td>
<td>2.49</td>
<td>2.49</td>
<td>0.00</td>
</tr>
<tr>
<td>Plasterboard</td>
<td>2.50</td>
<td>2.50</td>
<td>0.00</td>
</tr>
<tr>
<td>Plastic</td>
<td>1.61</td>
<td>1.61</td>
<td>0.00</td>
</tr>
<tr>
<td>Textiles</td>
<td>2.05</td>
<td>2.05</td>
<td>0.14</td>
</tr>
<tr>
<td>Wood</td>
<td>7.36</td>
<td>7.36</td>
<td>0.00</td>
</tr>
<tr>
<td>Total [t]</td>
<td>33.28</td>
<td>32.99</td>
<td>3.39</td>
</tr>
<tr>
<td>Percentage [%]</td>
<td>100</td>
<td>91.0</td>
<td>9.0</td>
</tr>
</tbody>
</table>

Fig. 5. Percentage (by weight) for each waste stream relative to the overall waste generation, for UCL Confinia Institute fit-out (fit-out SWMP, 2017).
5. Discussion and conclusions

Given the qualitative and quantitative analysis of non-domestic building fit-outs, it is clear there are several areas that can be improved. It was found that the supply chain for office and higher education institution (HEI) building fit-outs has a generic structure in which both decision and material flows show a predominantly linear tendency. The stakeholders in this supply chain with the highest impact on the specification of materials and components and the decision making on waste management are generally the client and the design team, while there is a discontinuity of communication and information across the supply chain.

Currently, good-practice fit-out projects (and the corresponding assessment methods) pursue high recycling percentages for the generated waste streams. However, this study found that the stakeholders in the supply chain are generally unaware of the waste streams’ final destinations, i.e., what the different waste streams get recycled into or used for. In the fit-out case study it was found that only 4% (150t) of material was closed-loop recycled out of 35.2t of waste generated during the fit-out process. The remaining waste was downcycled, while 2.2t1 were incinerated (for energy recovery), and 0.5t were used as compost. Out of the total, 42% (14.664t) of waste was exported abroad and the rest was treated within the UK. Waste final destinations were determined by market (prices) rather than environmental criteria.

The final destinations of building products are generally unclear as there is not enough evidence to ascertain what exactly happens to most material and components until they become something else. The main reason of this ambiguity is found to be the reduction of information across the supply chain. Waste is given to the Waste Collector, who in turn provides a waste report claiming the waste will be recycled at a given rate (e.g., 91%). The issued waste report serves as a measure for the recycling rate within a building process, or as evidence for an assessment method or certification scheme. However, neither the client, the certification schemes nor the government require data or evidence on the actual final destinations of the waste generated during fit-out processes. The waste path and the involved downstream supply chain are practically disconnected from the building process and its direct stakeholders in terms of communication and information.

During this research, there has been some reluctance from waste handlers to provide data on waste final destinations as this is deemed as commercially sensitive information. Moreover, data bases such as Eurostat (2018) do not provide information about recycling output, and the Environment Agency (Environment Agency, 2018) is not implementing strict auditing and standards on the final destinations of waste streams. Likewise, the material losses in the segregation and recycling process are not considered or reported. As the Sustainability Manager from the interviewed Waste Contractor stated: “without a standard how can you know they [the waste handlers] do what they say they do?”

Therefore, better mechanisms are needed to elucidate the whole path of end-of-life building products until they become something else. This feedback is important to better understand the paths of waste products and therefore be able to improve the circular performance. As well, it is pertinent to improve assessment methods or certification schemes so that these take into account building processes from a circular approach. Normally, rating systems assess the sustainability of waste management in terms of recycling rates, but require no evidence on how, where, or what the waste is recycled into. For instance, a PVC window recycled into another PVC building product by a local recycling site, is likely to be more sustainable than the window being transported a long distance (e.g., to China) and going into an uncertain recycling process.

The top-five waste streams generated during the fit-out case study were hardcore, mixed waste, wood, plastics and soot. The top waste streams collected during a three-month period by the interviewed waste contractor were gypsum, mixed waste, metals, wood, and glass. In both cases, mixed waste accounted for a significant share, even though the gate fee for mixed waste is generally
the highest compared to other waste streams. It is advisable for the General/Strip-out Contractor to segregate waste on site, and in fact, some segregated waste streams are collected free of charge or even paid for; it should be noted that waste from fit-outs gets recycled using European Waste Codes (EWCs) but these do not reveal which building materials and components the waste streams relate to.

The rate of waste generation (RWG) in the case-study fit-out was 12.17t per 100 m² of gross internal floor area (GFA). This is higher than the report values for offices of 6.4t per 100 m² of GFA, but lower than the average for HEI buildings of 33.7t per 100 m² of GFA. There are other indicators such as ‘m² of waste per 100 m² of GFA’, ‘m³ of waste per 1000 of project value’, and ‘tonnes of waste per £100 of project value’ (CIBW, 2009). The most widely used RWG indicator is ‘tonnes of waste per 100 m² of GFA’, which is the one used in this study, however there is no standardisation and there is some subjectivity to it.

This RWG can reflect the sustainability and efficiency of the resource management during the refurbishment process. RWG depends on the design of the fit-out process and outcome, but it also depends on the amount of materials and components installed in the building before fit-out, which is a pre-existing condition. Therefore, the amount of pre-installed items on site affects the RWG, but it is not intrinsic to the fit-out process and does not necessarily reflect on the quality of the resource management during the process, which makes this indicator subjective. Furthermore, there are heavier materials whose weight do not correlate with their environmental burden. For instance, concrete is heavier than insulation, but insulation generally presents higher environmental impacts, so having a tonne of insulation means higher environmental concerns than a tonne of concrete. Certification schemes like SCA Rating, BREEAM or LEED do not properly differ between the relative environmental impact of each type of material.

There are two different ‘circular’ paths regarding fit-out resources. The path of closed-loop recycling on one hand, and the path of reuse on the other end. Each of these paths require a different approach and entail different criteria to make them work. For instance, closed-loop recycling requires a reverse-logistic scheme which support the circular cycle and also requires product materials that are pure enough or can be properly separated to be recycled. Reuse is related to issues such as size standardisation, quantity, product type and availability of a reuse market. Better sharing/reuse platforms are needed so more reuse can happen – maybe a national sharing platform. Issues such as time, space and speed are crucial for the efficient implementation of reuse or close-loop recycling, and therefore, logistics result to be the common ground for both paths.

The findings and conclusions presented in this work are transferable to some extent to other types of non-domestic buildings, such as retail, hotels, restaurants and healthcare. In this context, the similarities among non-domestic buildings include: rate of replacement of interior materials and components (to some extent), design criteria of components in order to make them modular, reusable and recyclable, supply-chain scale, structure and trends, types of waste streams and their treatment, and the assessment methods used. On the other hand, some particular components differ (e.g. display cabinets in retail buildings) and the different use of the space may require additional considerations.

6. Scope and future work

The findings of this work are based on a set of interviewed stakeholders and involvement in four fit-out case studies – although only one case study is presented here. The study does not cover a comprehensive sample of the UCL building portfolio or fit-out practices in London. However, some findings of this work are transferable to the non-domestic fit-out industry.

The methodological approach encountered some barriers as several stakeholders were reluctant to participate or provide concise information. This work disregards critical materials which are contained in components such as fluorescent lamps and WEEE. Future work should consider critical materials and the financial value of material flows. This paper is presented with the expectation that a life-cycle analysis (LCA) would be conducted to assess the full environmental impact and identifying hotspots.

Acknowledgments

The authors acknowledge the support and the data provided by the interviewees and the corresponding stakeholders. The authors also thank the reviewers and the editors for their helpful comments. Finally, Miguel Casas-Arreondo acknowledges scholarships grant 324656 by CONACYT.

Abbreviations

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>BREEAM</td>
<td>Building Research Establishment Environmental Assessment Method</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>EWC</td>
<td>European Waste Code</td>
</tr>
<tr>
<td>GFA</td>
<td>Gross Floor Area</td>
</tr>
<tr>
<td>HEI</td>
<td>Higher Education Institution</td>
</tr>
<tr>
<td>HVAC</td>
<td>Heating Ventilating and Air-Conditioning</td>
</tr>
<tr>
<td>LCA</td>
<td>Life-cycle Analysis/Audit</td>
</tr>
<tr>
<td>M&amp;E</td>
<td>Mechanical and Electrical</td>
</tr>
<tr>
<td>PVC</td>
<td>Polyvinyl Chloride</td>
</tr>
<tr>
<td>RWG</td>
<td>Rate of Waste Generation</td>
</tr>
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<td>SWMP</td>
<td>Site Waste Management Plan</td>
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</table>

References


## B Qualitative analysis of interviews

### B.1 Layout of included interviews or communications

Table 0.1: Date, code and subject of personal interviews or communications included in the qualitative analysis.

<table>
<thead>
<tr>
<th>Date</th>
<th>Code</th>
<th>Subject</th>
</tr>
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<tbody>
<tr>
<td>07 November 2015</td>
<td>QA_01</td>
<td>Meeting [Personal name 22]</td>
</tr>
<tr>
<td>07 November 2015</td>
<td>QA_02</td>
<td>Meeting with [Personal name 61], [Personal name 40] and [Personal name 82]</td>
</tr>
<tr>
<td>13 November 2015</td>
<td>QA_03</td>
<td>Meeting with [Personal name 43]</td>
</tr>
<tr>
<td>27 November 2015</td>
<td>QA_04</td>
<td>Meeting with [Personal name 87] ([Company name 63])</td>
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<tr>
<td>23 January 2016</td>
<td>QA_05</td>
<td>Meeting no. 2 with [Personal name 22]</td>
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<tr>
<td>12 May 2016</td>
<td>QA_06</td>
<td>Meeting with [Personal name 52] from Goblechain</td>
</tr>
<tr>
<td>28 June 2016</td>
<td>QA_07</td>
<td>Site visit to [Company name 9] MRF</td>
</tr>
<tr>
<td>29 June 2016</td>
<td>QA_08</td>
<td>Meeting with [Personal name 29] from [Company name 15]</td>
</tr>
<tr>
<td>20 July 2016</td>
<td>QA_09</td>
<td>CircEL Workshop</td>
</tr>
<tr>
<td>12 August 2016</td>
<td>QA_10</td>
<td>Meeting with [Personal name 24]</td>
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<td>19 August 2016</td>
<td>QA_11</td>
<td>Meeting with [Personal name 41] from the Sustainable Heritage Lab</td>
</tr>
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<td>13 September 2016</td>
<td>QA_12</td>
<td>Meeting with [Personal name 42] from DIRTIT, Ben Croxford and [Personal name 9]</td>
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<td>29 September 2016</td>
<td>QA_13</td>
<td>Meeting no. 2 with [Personal name 24]</td>
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<td>13 October 2016</td>
<td>QA_14</td>
<td>Site visit no. 2 to [Company name 9] MRF</td>
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<tr>
<td>21 October 2016</td>
<td>QA_15</td>
<td>Questionnaire to Waste Contractor 1</td>
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<td>01 November 2016</td>
<td>QA_16</td>
<td>Questionnaire to Waste Contractor 2</td>
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<td>15 March 2017</td>
<td>QA_17</td>
<td>BauHow5 Workshop in Munich</td>
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<td>04 April 2017</td>
<td>QA_18</td>
<td>Workshop: Typology for construction components for reuse</td>
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<td>03 May 2017</td>
<td>QA_19</td>
<td>Meeting no. 3 with [Personal name 24]</td>
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<td>05 June 2017</td>
<td>QA_20</td>
<td>Meeting no. 3 with [Personal name 24]</td>
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<tr>
<td>22 July 2017</td>
<td>QA_21</td>
<td>Meeting with [Personal name 24] and [Personal name 9]</td>
</tr>
<tr>
<td>05 October 2017</td>
<td>QA_22</td>
<td>Meeting with [Personal name 18] (UCL Estates Strategy Manager)</td>
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<tr>
<td>10 October 2017</td>
<td>QA_23</td>
<td>Meeting no. 4 with [Personal name 24]</td>
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<td>26 October 2017</td>
<td>QA_24</td>
<td>Meeting with [Personal name 50] ([Company name 52])</td>
</tr>
<tr>
<td>15 November 2017</td>
<td>QA_25</td>
<td>Meeting with [Personal name 28] (UCL Waste Manager)</td>
</tr>
</tbody>
</table>

### B.2 Interviews or communications included in the qualitative analysis

#### 07 November 2015

**Code:** QA_01  
**Subject:** Meeting [Personal name 22]

[Personal name 22] – the idea of loaning and not owning, bricks or furniture for example

Could my thesis be a comparison of a circular fitouts against standard practices

The logistics is important, storage, bringing and taking

Warranty, repairing is a problematic issue

Premier sustain – offers furniture resale, donation, remodelling, refurbishing and recycling solutions
PVC only can be downcycled, also plastic releases toxic particles

Circular Economy does not take into account wellbeing (cradle to cradle), but considers resources

Focus on the use of the place, environmental psychology, people being comfortable with the changes, empathy, understand people’s needs

New HEI Ska considers: Corridors, cafes, labs, classrooms, all but accommodation

New Ska being launched in April

Cradle to cradle labelling, EPD Environmental Product Declaration, looking at the life cycle, life cycle, ingredients, have to present all –BRE

07 November 2015
Code: QA_02
Subject: Meeting with [Personal name 61], [Personal name 40] and [Personal name 82]

[Personal name 40] is chemical engineering –reusing components from C&D waste

[Personal name 82] -background is in energy –modelling, innovation policy, course director in energy and environment economics and policies

[Personal name 61] –Sincere project –started in April –China and Europe, Gain Jong (knows the most about CE in China), his backgrounds are in metrics –this project is about indicators, history, modelling and policy –Lin Gan: ecoindustrial park –studying a macroeconomic model on CE –mentioned industrial symbiosis

Ucl.ac.uk/sincere

[Personal name 82] -China is less focused on CE materials and more in pollution, resource efficiency agenda is less present

[Personal name 61] -Emergy

[Personal name 61] –the project -upscaling business models, deadline 8th march

Eco-inovera –Dutch contact, co-partners TNO the Dutch CE association, Tecnopolis (consultancy), CIEE consortium of Italian environmental... waste management

[Personal name 6], was director of TNO, now director of TU Delf CE

[Personal name 40] –asks if is directed towards business or economy and what kind of business apart of leasing

Ben Croxford –commented CE 100

Ben Croxford –ecoeurope, meeting with them tomorrow, doing a project of doing boards out of cellulose † East London biogas

[Personal name 51] –they need specific case studies of business being done in an innovative way –eco-cement business
Ben Croxford –should ask the business school to integrate and give their perspective, Institute Globe Prosperity

13 November 2015
Code: QA_03
Subject: Meeting with [Personal name 43]

- [Personal name 13] –did a PhD thesis on refurbishment
- Cross laminated timber
- System consolidators – contractors and designers – contractors are less resilient
- Consider agents
- How many people use Ska – who drives the adoption – what’s the uptake – to know how I could influence
- Mayor impacts are the foundations, structure and envelope
- Screed – in flooring
- Wait for link to article
- An idea could be to provide a database to make info more available
- Ongreening, specified by – database for materials
- The quartz project – google and other partners
- Veladrome
- The Adaptive Truss

27 November 2015
Code: QA_04
Subject: Meeting with [Personal name 87] ([Company name 63])

Webinar – Growing Better Buildings – Biocomposite materials

PROCESS
- These materials use fibre + resin
- Using residual waste from plants not to compete with food demand
  - The resin comes from sugar cane, derived from gas (VAGSSA... something like this)
  - The fibre comes could come from jude, hemp, flex, seisel, cotton, etc.
- See Furan resin for further information (there are articles about this)

PERFORMANCE
- They have made acoustic and resistance tests
The acoustic performance is good (they add acoustic insulation), but should be careful that the sound doesn’t filtrate through ceiling or roof. Mentioned something about flanking.

- Interior components (partitions) last at least 10 years. They are still thinking it is better to improve the lifespan as to be able to reuse them.

**RECYCLING**

- When recycling, should separate the technical components such as rubber or nails and the biological components.
- There are three options after use:
  - Grind and use them for filling or for concrete mixing.
  - Recycle by separating resin (heated and melted), fibre, and chemicals.
  - Using them for compost.

**COST**

- The cost are currently higher but if it was industrialized it could be around 20% cheaper in the future.
- The maintenance cost would be lower.
- They could be commercially available within 6-12 months, depending of funding and approval.

**CERTIFICATION**

- This kind of materials are have no codes, standards or guidelines.
  - Are not fully taken into account in LEED or BREEAM.
  - In 5 years the European Commission will push this forward.

**USES**

- Appropriate for cladding.
- Also for interior components.
  - Partitions (already being developed by them).
  - Furniture as tables (look it up on google).

**ADVICES**

- Should quantify my project from a cost/financial perspective, because this is what drives its development and uptake.
- *He has an office in London (can meet him if needed)*

**23 January 2016**

**Code:** QA_05

**Subject:** Meeting no. 2 with [Personal name 22]
Sign to Building Centre newsletter

Ska is more cost effective in its assessment and the relative costs, and user friendly/practical

[Company name 23] –big company that does lots of things related

CHECK case studies in SKA website

Brazil –issues –different weighting –hardwood was number one instead of energy

UK building control-not in brasil

Better SKA Uptake by tenants, contractors, engineers, suppliers (not by designers)

SKA benefits: Operating costs energy and water, not much savings in materials, productivity increase –indirect benefits

Capital allowance gets reduced from corporate taxes if using Energy Technology List (ETL) criteria (in-land revenue, gov department that takes care)

References may be invoices or delivery notes, they are inserted generally by the assessor

Contributors may edit but they cannot change scope, owners can do everything

Keys to a good assessment: communication, get it as early as possible –design team

She showed me the numbers of the online tools uses and numbers official assessment for 2015

12 May 2016
Code: QA_06
Subject: Meeting with [Personal name 52] from Goblechain

- This company is what she calls freecycle
- They get big volumes waste from commercial (retail) and construction
- Then they sell it to other companies, they work with [Company name 2], NHS, [Company name 36], [Company name 17], [Company name 20], WRAP, etc
- They’re developing a take-back scheme to collect waste using [Company name 19] Vans
- Ben Croxford mentioned an idea he heard from a student to use 3-d recognition to know what kind of components/waste you have

28 June 2016
Code: QA_07
Subject: Site visit to [Company name 9] MRF

Hosts: [Personal name 8] [Personal name 8] and [Personal name 19]

- [Company name 9] is a privately owned company; started in 1919
They’re just one step in the chain as they later give the materials to someone else to recycle or use them

They work regionally for London and southwest of UK

As for 2016 it has two facilities in west London (Bow) comprising about 16,500 sq m each

The attain 92% recycling with a speed with a rate of 120 tons p/hour (when machines are working)

They’ve just installed a 1 MW solar panel system

They got a new machine to separate paper by infrared technology which uses refractive indexes of materials

They have other machines for separating plastics they designed themselves

- Untreated wood gets recycled while bad one goes to energy (separated by hand)
- They work with plasterboard (along with British Gypsum). They take away the contamination in the plaster by human hand and with electromagnets (for metal particles) and then give the material to British Gypsum
- The process in general is as follows:
  1. Waste gets in (they measure the waste with a giant vasculue on which the ingoing trucks stand; also the outgoing waste gets measured)
  2. Waste gets checked by the pickers
  3. Then they use the trummel to rotate the waste and fine materials fall through the gaps (<14mm)
  4. They use a cyclonic system in which heavy material goes down
  5. They use some kind of inclined band in which heavy goes down and light (as paper) goes up
  6. Infrared separation, determines what should remain on the band and what goes automatically thrown down to the sides

29 June 2016
Code: QA_08
Subject: Meeting with [Personal name 29] from [Company name 15]

- They are waste managers; they achieve an 85-95% diversion to landfill rate
- He mentioned they’ve worked more with BREAM but also with SKA
- They charge about £110-120 per ton of waste collected, he says in the future client should be more benefited from this by not having to pay or even receiving money for their waste
- They use third-party transportation to pick-up and deliver the waste (such as companies as [Company name 9])
The clients are the most important actors as they chose whether to have circular fit-outs

Landfill taxes is the way to do it, this is a very important incentive which has encouraged the shift towards circular waste. Ten years ago landfill tax was half the price around £45 per ton; nowadays is £95

There’s not direct connection between start-point in the waste stream (where waste is generated) and endpoint (where the waste gets reprocessed into new materials); so they see a bit potential in closing this loop properly; they’re aiming for that

One of the major problems is logistics, both transport and space

Even though they see a very high rate of recycling in their projects, there is little reuse, except:
- Some tiles (carpets and ceilings), lighting and furniture gets donated to organisations such as scouts

In their projects, fit-out companies are the ones which remove the building components, so he couldn't help me in that regard, but he might introduce me to [Personal name 31], Sustainability Manager from Paragon Fit-outs

Saint-Gobain (which owns British Gypsum and Armstrong Ceilings) wants to increase the recycled content in their glass by 25% (driven by costs benefits)

[Company name 5] at Essex is an important glass recycling company who they work with

20 July 2016
Code: QA_09
Subject: CircEL Workshop

Furniture and Wood Reuse

Participants

Ben Croxford (moderator); [Personal name 52] (Globechain, CEO); [Personal name 23] (Community Wood Recycling, Enterprise Development Coordinator); [Personal name 25] (JPA, Sustainability Director); [Personal name 79] (UCL Sustainability Team, Sustainability Manager); Miguel Casas (note taker).

Introduction

- May: Globechain is a freecycle. They get big volumes of retail and construction waste and sell it to other companies. They work with companies such as [Company name 2], NHS, [Company name 36], [Company name 17].
- Elizabeth Green: Community Wood Recycling is a 28-members freecycle. They go to construction sites, take all the wood, categorise it (top wood gets reused), and make
it into furniture, or chop it off for energy recovery. They employ people from all backgrounds.

- [Personal name 25]: Most of JPA furniture is wood. UCL has had a long relation with them because they are adaptable and produce robust products. They provide maintenance support for their furniture, making it last longer. They also have a recycle centre (Camden collect-it).

- [Personal name 78]: Furniture reuse is on the agenda of the Sustainability team. They aim to make reuse become mainstream.

**Roundtable discussion main points**

Advantages (of furniture and wood reuse):
- Avoids costs in disposal.
- Furniture reuse and donation can upskill people and increase employability.

Barriers:
- Logistics for this purpose is costly, carbon intensive, and might also be complicated.
- Wood building components are not standardised, so it is difficult to reuse them in subsequent projects.
- People generally perceive used products as low quality or out of fashion.

Questions raised:
- What to do with the construction on-site wood off-cuts?
- What to do with the packaging?
- What to do with less good woods?
- How to separate treated from untreated wood?

Ideas:
- Include labels with ingredients/components in furniture.
- 3D automated recognition of furniture.
- Furniture leasing instead of selling (Elizabeth said this is already taking place in a few instances).
- Engage with new business models.
- Logistics/take-back schemes similar to Uber to facilitate reuse uptake.

12 August 2016

**Code:** QA_10

**Subject:** Meeting with [Personal name 24]

- Mentioned is friends with [Personal name 38] from [Company name 33] Potential UCL fit-out projects
- Here East, has been delayed because of overbudget, waiting for contractor to be assigned. [Personal name 24] will put me in contact with contractor and with Project Manager from [Company name 25] (which he says is a nice guy).
  - There will be construction waste like cut-offs, no major strip-out since it’s pretty empty
- St. Martins Legrand (near St.Pauls cathedral) – Ska scope meeting in September
  - Will be office fit-out, over 100 desks, construction waste, NO strip-out
- Torrington Place groundfloor – ska scope meeting on the 13th of Sept @9:30-12:30
  - It’s currently offices, there WILL be strip-out and will be turned into teaching space
- Bloomsbury Theatre – will be finished in summer ’18, in January will be decided what to do with it. This will be massive refurbishment

Briefly explained how supply chain works:

19 August 2016
Code: QA_11
Subject: Meeting with [Personal name 41] from the Sustainable Heritage Lab

Showed me three spectrometers

- FTIR (Fourier Transfer InfraRed) Spectrometer
  7. Box about 40cmX30X15, you put the material as you’d do in microscope (kind of pressing it), also has interchangeable part to be able to put material just next to it

Infrared spectrometers

8. Can detect type of material, its spectrum curve matches one of the samples in the library (their library is commercial)
9. Often used in metal objects to measure percentage of zinc, aluminium, etc.

10. Can also detect degradation

11. Produces a spectrum curve: x-axis is Wave no (frequency), y-axis is Intensity (% reflected)

12. This works because different chemical bonds absorb different wavelengths of radiation. Chemical bonds are like springs and they vibrate when a particular wavelength is applied. When a chemical bond vibrates it means it’s absorbing, so certain chemical bonds absorb certain wavelength.

13. The above is given by \( E = \frac{hc}{\lambda} \), where h is the Planck constant, and c is speed of light.

14. Flat box, a little bigger, has an optic fibre cable attached which beams the IR light and also detects the reflected percentage

15. Can be used to measure PH through a regression

16. Head of UCL Department of Statistics, told [Personal name] about the current use of Near Specs. in plastic recycling process to identify types of materials.

17. Often used in metal objects to measure percentage of zinc, aluminium, etc.

18. It has nothing to do with chemical bonds but with electrons being detached from atoms

**13 September 2016**

**Code: QA_12**

**Subject: Meeting with [Personal name 42] from DIRTT, Ben Croxford and [Personal name 9]**

[Personal name 42] is originally Canadian, from Calgary. The factories are in the USA. They do business in Ireland, UK, France, Middle East, Canada and USA.

Adapt produces ergonomic furniture, the respective owners are brothers.

**DIRTT**

Founded 12 years ago

They use LEGO system – Pre-engineered interlocked components

To assemble they use zippers and ziplocks: Hanger (top) fits in the Antler (the hanger extrusion), while the Clip (bottom) fits in the Angus.

Use a software called ICE, to design (2D and 3D visualisation), and define costs and times. They can integrate ICE with BIM and ISC standard
Use blankets as packaging that are reused

They can install touch-capacity walls and sound-amplifying tiles

The boards are composed of aluminium frame + recycled denim + MDF tile, walls can be 2 or 4 inch wide

The boards’ finishings are willow glass (two-hair thick) that can be printed on

All boards and tiles are bar coded

They don’t yet have a take-back scheme but are thinking about it. What they do is they send emails around to see who is interested in the components they remove

They render in virtual reality. Currently working in setting it with Google glasses, which can scroll down lists to make instant changes

[Personal name 42] (DIRTT) mentioned interior changes in order to accommodate changing uses

[Personal name 42] said they can provide a license for the ICE software

29 September 2016

Code: QA_13

Subject: Meeting no. 2 with [Personal name 24]

Confucius project is still pending – about to assign contractor

They might use a strip-out contractor

Also Torrington place is pending – the strip-out haven’t been done yet

In the Bloomsbury theatre they had to do a quick strip-out as they found asbestos

About the question I made: To proof the recycling/reuse rate in fit-out assessments, waste report from waste contractors is used

They might say they recycle but they generally DO NOT break it down, so you can’t know what they do with the waste in detail

Contractor makes the Site Waste Management Plan and waste contractor gives the actual results

[Personal name 24] showed me some spreadsheets from PEAK, fit-out contractors

Also showed me a spread sheet from PROWASTE, Steve Lawn is PROWASTE Environmental Manager

Ska office requires a 90% recycle while HEI aims more to reuse

[Personal name 24] gave good idea:

PAST – If looking at the past fit-outs I see there’s NO WAY OF KNOWING what exactly happens, this can be interesting finding – e.g. 97% was recycled but was it downcycled or what…
PRESENT – I look at ongoing projects and find information that I could see in previous projects

FUTURE – Considering the info I gathered from present, how can fit-outs can be improved in the future, maybe I can be the waste person in these

Speaking about the Present findings – what are the barriers, is it the manufacturer?

Camden borough requires BREEAM from design for new buildings

CEQUAL is the civil engineering certification

[Personal name 36] works at [Company name 33], [Personal name 24] knows her

[Personal name 24] will send Canary Wharf’s fit-out project information

I should find worst/average practice case studies in order to compare

[Personal name 24] goes one week on a leave from 10th October

13 October 2016

Code: QA_14

Subject: Site visit no. 2 to [Company name 9] MRF

[Personal name 8], [Personal name 13], [Personal name 4] and me, guided by site Manager ([Personal name 8]), It was rainy. [Personal name 8] bought us burgers, we had a chat at the lunch

They collect waste mainly from businesses ([Personal name 8] mentioned [Company name 53] and [Company name 54])

About 40% of incoming waste is collected by them, and 60% is brought by other collecting companies

They charge about £100 per ton, while landfill charges about £120 per ton (including landfill tax)

In the facility no. 1 (the outdoors muddy one) they receive general waste

In no. 2 (indoors one) they receive domestic/office waste

They do not accept: hazardous, clinical, liquids, and tires and plasterboard. The two latter have legislations which require closed-loop recycling (British Gypsum is main plasterboard recycler, but only accepts their own)

The overall process at facility no. 1 is:

- Waste goes to the Pickers station where there is a moving band and about four guys are hand-picking the following: metal, wood, bricks, and comingle (plastic, cardboard, paper)

- The remaining waste goes to the trummel (massive rotating cylinder) where the soils and small particles, called the Fines, get filtered to the ground

- Whatever is left gets compressed and packed in cylinders (called Bails) and is sent to Holland go become waste to energy
19. Hand-picked recyclables are sent to different recycling facilities. They don’t get glass since glass is normally separated by other people before sending the waste.

1. Wood is not separated by grade. Wood is generally sent to a specialised recycling facility called Connect in Dagenham

2. When they receive construction waste, they don’t mount it on the Picker station, but they separate directly on the ground by Grabs (caterpillar machines).

20. They fill-up 36 curtain-side-trailers each week for waste to energy. Each trailer carries 25 tons (42 tons including trailer’s weight). They send the Bails to Holland just because it’s cheaper.

21. The Fines are used for covering landfills every day or to back-fill holes (like in a golf course).

Facility no. 2 has a different process, they use pickers but also specialised machines to separate recyclables.

Random facts:

The containers are called Skips

[Personal name 8] says (while driving with him and at lunch):

Moving waste around London costs about £100-£150 per load. Is more cost-effective to use large trailers

In Waste to Energy facilities, only 25% is actually electricity output. Out of the 75% remaining, 80%-90% can be recovered as heat for district/water heating.

Showed us a website called ReYooz.com (beta testing), which is for business giving away stuff they don’t use. He says this is not Freecycle, as Freecycle is a peer to peer process -> from Reyooz.com> Reyooz saves your organisation an average of 20-30% on equivalent waste disposal costs and saves 100% on purchasing and procurement.

Colin mentioned a web US web called Stuffstr, which keeps track of people’s belongings (how long they keep the stuff, how long item lasts) and sells this info to manufacturers.

21 October 2016
Code: QA_15
Subject: Questionnaire to Waste Contractor 1

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<td>21 October 2016</td>
<td>[Personal name 3]</td>
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<td>[Company name 29]</td>
<td>Sustainability Assistant</td>
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PROJECT BRIEF: The project “Circular Economy in Office Building Fit-outs” is carried out in the UCL Environmental Design and Engineering Institute, by the PhD student Miguel Casas and supervised by Dr Ben Croxford. The project aims to trace the paths of different waste streams throughout the supply chain involved in fit-out projects, in order to identify potential improvements regarding sustainability. We appreciate your collaboration; all information will be treated as confidential.

PLEASE ANSWER THE FOLLOWING QUESTIONS FROM YOUR OWN PERSPECTIVE AND EXPERIENCE:

1. What are your main roles in the company?

I am a sustainability assistant. I do management systems, BREEAM, SKA, and LEED (which is becoming more common), pre-refurbishment audit, internal audits, manage projects. For instance, in a certified project, he would go on-site, identify recyclables, may do consulting beforehand (tell them how to do the waste management: mainly sorting), then he’d go on site and make sure they are where they have to be [they are doing what they should], he’d sit with the sustainability team and they would tell him where they’re at. As a waste manager they deal with construction and demolition waste, not food no other

2. What percentage of the waste that your company collects comes from fit-out projects?

Will Come back

3. Is there a significant disparity in the waste management among different fit-out projects in the UK? Approximately what is the highest and the lowest landfill diversion rate for fit-out waste?

Not that different. That would depend on the waste company they use, small skip companies would not have the infrastructure. The more you can segregate they more you can recycle.

4. Do you think landfill tax is the main driver for landfill diversion?

Yes and no. It is pushed by environmental agenda and client’s agenda, it’s a key driver but not the only.

5. How low would the landfill tax need to be to make landfilling the preferred option or how high would it need to be to avoid any landfilling in fit-out projects?

M: Doesn’t matter. As long as landfill is a little bit more expensive

*Polystyrene has to be incinerated, but they don’t get a massive amount of it.

6. How would you rank the different waste treatment options according to cost (from lowest to highest)? (e.g. 1. Waste to energy, 2. Recycling, 3. Landfilling, 4. Reuse)

M: Reuse, recycle, incineration, landfill, the last two are probably the same. Although incineration is cheaper, the cost is to get the material right [in the proper conditioned to get incinerated] so it's nearly equal.
7. What percentage in average of the fit-out waste that your company collects gets recycled, reused, incinerated, and landfilled?

96-97% overall recycling percentage, if it’s segregated it will be a 100%.

8. What are the types of waste that your company collects from fit-outs? Which of these are the most common?

M: Timber is the main one, plasterboard is a key one [also very common], packaging, raised floor tiles, carpet tiles, not so much metal (M&E, light fittings, ductwork, tubes), a bit insulation.

9. What are the rates that your company charges for these different types of waste?

M: How much they charge for taking the waste from costumers:

- Landfill would be £100
- Mixed waste £80 [I think this is what he said, not sure]
- segregated plasterboard £60
- wood £50 p ton
- concrete rubble, client gets paid £FOC [fee of charge] to £5,
- Plastics, metals, cardboard, paper, client gets paid... FOC to £100 p ton

How much they charge for other companies tipping waste there:

- Mixed waste £100
- Segregated wood £60
- Segregated plasterboard £80

20% cheaper in average to have a segregated skip

They wouldn't receive metal from other, cause metal can be taken elsewhere and get paid for it

Letsrecycle.com... will give me guidelines

10. Could all of these types of waste get recycled or are there some of them that cannot be recycled?

Yes. [I asked about mercury in light tubes he said he would show me the machine that extract the mercury out of it, but didn’t show it to me].

11. How do you measure the waste coming from fit-out projects? (e.g. by weigh, volume, container, etc.)

By weight, every skip or lorry is weighted when coming in and the empty one is weighed again when out.

12. How does your company manage the waste collected? (e.g. spreadsheets, data bases, etc.) Do you compare these records against the fit-out contractor’s waste management plan?

Each project has their own recycling report: total waste collected in KG, and total waste recycled. [He showed me and will sent and example]
13. Does your company store the waste after collecting it or is it immediately delivered somewhere else? If waste is indeed stored, where does your company store it?
Will be stored on site, and get sorted and sent to respective destiny in a continuous process.

14. Does this waste generally get mixed with waste coming from different sources?
Yes, but you measure from every project, the weight and the segregation level before.

15. Does your company have the facilities to carry out the recycling of the collected waste?
[Of course they have so I asked how much of their waste they collect themselves] We collect the vast majority, some others do tip their waste here. We have 46 lorries collecting from their own projects. [I asked if all goes to that site] It all comes to this facility.

16. Where does your company take the waste to be recycled and/or incinerated? What are the rates that the recycling facilities charge or pay for each type of waste?
One different one for each waste stream [will give me contact details]

17. Why do you consider waste contractors often do not carry out the recycling themselves, and recycling facilities do not perform the waste collection by themselves?
Because they don’t have the infrastructure… like floor tiles it’s difficult to recycle.

18. Do you know what the different waste types get recycled into in the recycling facilities? Could you provide some examples?
It’s duty of care so they do know what’s happening to them, what exactly happens, so they audit.

19. How do you consider strip-out contractors could contribute to a more efficient waste management? (e.g. more careful removal of building components, better waste sorting, etc.)
They have a stip-out division. All sites have their own pressure (time and budget)... if they can segregate that would be good, but you need space. They all have different incentives, if you segregate it’s normally cheaper (financial incentive), but it’s different for everyone.

20. Who do you consider generally makes the decisions within the fit-out supply chain on how to manage the waste? Which roles within this supply chain have the greatest effect on waste management?
Project Manager, QS (financial), Env. Team. [when I asked if it depends all on the design team he said it’s generally in the upper levels]. [Company name 29] don’t get involved with the design team.

21. Which do you think are the main barriers for recycling and reuse in fit-out projects?
Quality of materials that come out, e.g. can reuse carpet for safe walk in construction sites… Space, if you have no space you cannot segregate.... Education on the guys on the site.... [I asked whose education he said] strip outs’ responsibility… If they, [Company name 29], did
the strip out with BREEAM, they would to a pre-audit… If tables are good they would recommend to reuse (to the main contractor), or donate to charities, tables, carpet tiles, doors…

If they do the strip-out, the logistics, and the waste…. He would go to the strip out site and identify recyclables … if you have three companies with their own agendas is more difficult…. It’s a lot easier with only one company involved.

On the other hand, if you got two companies the responsibilities is half, you got two companies thinking on it; principal contractor has to be in charge on everything, so whatever is easier for them.

22. How do you think waste management in fit-out processes can be improved?

If it’s one company… not so much actors in the supply chain [as stated in previous question]

If you give each fit-out a certification like Ska or BREEAM… that forces it to be better…

[I asked which certification method is easier to follow] Ska is hell of a lot easier, well as a waste contractor is pretty much similar cause they only have to focus on one section on BREEAM… If you speak to principal contractor they would say ska is easier, but should ask a principal contractor on that one.

23. Which aspects of waste management do you consider should have further governmental regulations?

Set achievable, objective but progressive targets…

Can’t force SKA or BREEAM. If you make Ska compulsory it would encourage monopolising…would kill the small guys… that’s not sustainable.

01 November 2016
Code: QA_16
Subject: Questionnaire to Waste Contractor 2

Note: Although this interviewee registered the date as 19-10-2016, the Q&A was emailed to me on 01-11-2016.

Questionnaire to Waste Contractor

Date: 19th October 2016
Name: [Personal name 46]
Education: BSc ITMB
Contact: [personal phone number]
Company: [Personal name 27]
Position: Resource and Development Manager

PROJECT BRIEF: The project “Circular Economy in Office Building Fit-outs” is carried out in the UCL Environmental Design and Engineering Institute, by the PhD student Miguel Casas and supervised by Dr Ben Croxford. The project aims to trace the paths of different waste streams throughout the supply chain involved in fit-out projects, in order to
identify potential improvements regarding sustainability. We appreciate your collaboration; all information will be treated as confidential.

PLEASE ANSWER THE FOLLOWING QUESTIONS FROM YOUR OWN PERSPECTIVE AND EXPERIENCE:

1. What are your main roles in the company?

My job roles within [Company name 27] are rather extensive, I open up and start new contracts both with clients and new suppliers whilst supervising and overseeing logistics. I monitor our supply chain very closely, issue waste reports and manage document control. I handle the companies’ health and safety, quality and environmental management.

I work very closely with our clients environmental and sustainability teams.

2. What percentage of the waste that your company collects comes from fit-out projects?

90% of our work is from Strip Out and Fit Out projects, majority of the strip out projects then become fit-out projects so the line between the two is hard to define.

3. Is there a significant disparity in the waste management among different fit-out projects in the UK? Approximately what is the highest and the lowest landfill diversion rate for fit-out waste?

Yes, this depends on the firm doing the fit out and their client’s requirements. I cannot comment on other waste management firms, however we at [Company name 27] have a 100% landfill diversion and this has been maintained for many years, this is due to the types of materials we collect (we do not handle municipal waste or domestic waste) alongside our established supply chain which has some of the best material recovery facilities in London.

4. Do you think landfill tax is the main driver for landfill diversion?

I do not believe it to be from our perspective, of course the cost is increased, but this is just reflected to the clients. I believe it to be down to better environmental awareness and the changing demand our customers face from their clients. With such accreditations such as BREEAM, SKA and LEED whom not only expect/demand a maximum diversion from landfill but a minimal amount of waste recovered as an alternative fuel (incineration), with more and more emphasis being focused on reusing materials and reducing waste production.

5. How low would the landfill tax need to be to make landfilling the preferred option or how high would it need to be to avoid any landilling in fit-out projects?

Landfilling is not an option. As I say from our perspective it’s not all about the cost it’s the ethics and the growing requirements from our clients to achieve high levels of reuse and higher recycling rates, whilst they (our clients) are also reducing the waste produced. As a company by helping our clients achieve this we benefit from repeat business and any cost increases are reflected to our clients.
The materials we handle such as plasterboard, wood, plastic, metal, glass, carpet tiles, raised access flooring, ceiling tiles, insulation, etc., all have a designated strategy to manage and recycle, with a large emphasis placed on trying to reuse these materials either in-situ or off site. We also have business to business relationships established with manufactures to ensure closed loop recycling, also providing take back and end of life schemes.

6. How would you rank the different waste treatment options according to cost (from lowest to highest)? (e.g. 1. Waste to energy, 2. Recycling, 3. Landfilling, 4. Reuse)

1 – Reuse, 2 – Recycling, 3 – Recovery

7. What percentage in average of the fit-out waste that your company collects gets recycled, reused, incinerated, and landfilled?

This is difficult to answer as each job has very different outputs. Specifically regarding fit-out. By average of “Fit-out” – 95/98% Recycled, 2/5 % recovery, 0% landfill. This is all proportional to the amount of materials/waste produced at site. We have jobs that output 1000’s of tonnes and some that output 10’s of tonnes. Of course with a strip out the reuse is a lot higher, with fit outs its materials going in so reuse is very unlikely as products are purchased to be put in, so the focus with fit-outs should be on waste reduction initally.

8. What are the types of waste that your company collects from fit-outs? Which of these are the most common?

If the site is not segregating then their wastes will be mixed waste. If the waste is being segregated, which we promote, then the wastes streams are likely to be: Plasterboard (Most Common), Metal (Most Common), Wood (Most Common), plastic, insulation, cardboard/paper, polystyrene.

9. What are the rates that your company charges for these different types of waste?

I will not be discussing rates I am afraid.

10. Could all of these types of waste get recycled or are there some of them that cannot be recycled?

Everything can be reused, recycled or reduced if you have the right suppliers; this is only with reference to the material we handle from strip outs. Worse case is materials we handle that cannot be recycled are then sent for recovery as an alternative fuel (Energy Recovery, which for most of our clients, a high percent output of recovery is an unacceptable).

11. How do you measure the waste coming from fit-out projects? (e.g. by weigh, volume, container, etc.)

Measurement method is determined by the collection type: Compactor, Cage Lorry, Bin Exchange, Skip, in all instances we have a container volume and a weight supplied from both the transfer station weight bridge and our vehicle scales (between these three attributes we can fine tune our final weight data output).

12. How does your company manage the waste collected? (e.g. spreadsheets, data bases, etc.) Do you compare these records against the fit-out contractor's waste management plan?
All collections have an associated waste transfer note and a weight bridge ticket, this captured data is then inputted into our database where it can be monitored, tracked and reports can be raised. We then issue these waste reports out either weekly or monthly to our client who use them for their waste management plan.

13. Does your company store the waste after collecting it or is it immediately delivered somewhere else? If waste is indeed stored, where does your company store it?

Majority of all waste we collect goes immediately to the relevant transfer station or material recovery facility. Any waste that does return to our depot is managed in bins and bays where we segregate the waste and load the segregated streams in to dedicated skips, compactors and cage Lorries for transfer the following day.

14. Does this waste generally get mixed with waste coming from different sources?

No, If waste is segregated then we keep it segregated, we promote segregation and its company policy to segregated and we will not mixed segregated waste. Of course if the client gives us mixed waste then it is treated as mixed waste for our client. If we as a company can segregate the waste before it goes for processing then we will.

15. Does your company have the facilities to carry out the recycling of the collected waste?

No, we have the facilities to transport and segregated waste, but we do not process waste.

16. Where does your company take the waste to be recycled and/or incinerated? What are the rates that the recycling facilities charge or pay for each type of waste?

This is down to our suppliers, of course we vet all our suppliers and they all use different methods and suppliers. I would have to write you a short essay to explain the whole process. Again I will not discuss costs or expenses.

17. Why do you consider waste contractors often do not carry out the recycling themselves, and recycling facilities do not perform the waste collection by themselves?

It’s about efficiency of the process, we can ensure our commitment lays with collecting our clients waste as they require and when they require ensuring a smooth waste collection service. Whereas recycling facilities need to meet targets so they need to focus on these targets and the process of send materials to their buyers/suppliers. I cannot speak for them, but I can say we deal with collections of 10’of tonnes, where as I know recycling facilities deal with 1000’s of tonnes and need to maintain that target so they will deal with very large waste contracts, but they need third parties to bring waste in to ensure that meet their targets.

18. Do you know what the different waste types get recycled into in the recycling facilities? Could you provide some examples?

Yes I do, however there are many and this answer would be a short essay, I do not have the time sorry, but the information of such is readily available for you during research.

19. How do you consider strip-out contractors could contribute to a more efficient waste management? (e.g. more careful removal of building components, better waste sorting, etc.)
They need to consider material on initial purchasing and to reduce the waste produced when installing and constructing the fit-out. It’s recommended that they implement pre-refurbishment audits with their waste management contractor so that a plan can be drawn up prior to the start of works, this way they will receive the waste management knowledge they need to proceed in the correct manner and the waste contractor can prepare for the best practice for the waste streams that are going to be produced.

20. Who do you consider generally makes the decisions within the fit-out supply chain on how to manage the waste? Which roles within this supply chain have the greatest effect on waste management?

Environmental and sustainability teams are more and more common with fit-out and strip out firms, with more and more of their clients requiring achievement for environmental accreditations. So it comes down to the company’s ethics, set-up, clientele and overall mission statement.

21. Which do you think are the main barriers for recycling and reuse in fit-out projects?

The initial approach, firstly the strip-out/fit-out firms strategy, their client’s demands and the site (size, restrictions, noise, dust etc.). All of these determine the overall strategy at site. The good thing is that our customers are becoming more and more environmental aware and their clients are demanding much more environmental and sustainability proficiency.

22. How do you think waste management in fit-out processes can be improved?

Fit-out firms working much closer with their waste management supplier, usually the job is all planned prior to getting a waste firm in. If the waste management supplier was to visit site and/or talk closely with the fit-out team, this will allow for the correct material segregation on site, initial set up of end-of life and take-back schemes. The waste management firm can supply there expertise to advise the treatment of materials and the best way to approach on site segregation.

23. Which aspects of waste management do you consider should have further governmental regulations?

There is no set standard, all waste firms accredit a permit from the environmental agency be it a waste management permit or waste carriers license, however without a standard how do you know that the waste firm are doing exactly what they are saying.

15 March 2017
Code: QA_17
Subject: BauHow5 Workshop in Munich

I assisted this workshop in TUM (Munich) from 12th to 15th March 2017, along with Ben Croxford, also [Personal name 13] was there.

The 5 participating universities were: UCL, TUM, ETH Zurich, Chalmers Univ., TU Delft

I presented a summarised upgrade presentation, and I received the following feedback from [Personal name 10]:

Dear Miguel,

Below and attached a few first leads I thought of. In general, the preliminary conclusions you provide – including the required shift from linear to circular supply & value chains on slides 16-19 – are correct and confirmed by precedent analyses (as far as I know, I am not that familiar with the specific UK context). This is where the conundrum starts, which comprises of technical and design questions but mostly boil down to organisational, financial, legal and behavioural issues. Potential change agents are dispersed over the value chain, the answer is in ‘shared value’ in all its diversity. Think of the lighting solution of Turntoo with Philips on one end of the spectrum, and the work of e.g. Rotor and Repurpose on the other. A really valuable part of your work it seems is the fact you aim to quantify material flows and the impacts of circular, regenerative alternative concepts. The need for such quantified data is tangible everywhere: coming up with innovative models, so appealing they make the current ones redundant, is one thing, but providing scientific evidence those concepts are better from an integrated – social, ecological, economical – perspective is another.

04 April 2017
Code: QA_18
Subject: Workshop: Typology for construction components for reuse

Ben Croxford sent me the email, which he received from [Personal name 13], which in turn he received from [Personal name 72]. The workshop was divided into two groups, I was with [Personal name 13], [Personal name 72], a guy name [Personal name 58], another guy and [Personal name 83] (University of Leeds) who is the main researcher on this project. I arrived late but participated in three sessions: 1) discussing amendments/additions to typology categories; 2) discussing structure in general (whether is enough, too much, or whether it should be different for different kind of components, etc.; 3) barriers and opportunities

[Personal name 82] (from University of Leeds) raised the points:

- What is material? What is component?
- Are you recovering material or function?
- What drives reuse? What drives certification?
  - maybe virgin materials being so expensive
  - maybe regulations which aim to -protect the environment, -encourage the conditions for markets to exist
- Someone mentioned, it is difficult to know what materials there are in old buildings, there are no plans or blueprints
- [Personal name 13] mentioned waste gets recorded in classifications (EWC) but this does not reflect what building materials/components they are – should make this categories compatible
- A true environmental impact of reuse has not been assessed
Barriers and incentives (which were broken down into Environmental, Economic, Social, and Technical):

- Landfill tax can be seen as both barrier because inert waste is too cheap to landfill (£2.4 p/ton)
- LCA does not cover social and economical aspects - I asked [Personal name 83] if she’s heard of IO-LCA, she said that’s what they use at Leeds
- [Personal name 57] mentioned pre-cycling insurance as an economical opportunity
- [Personal name 72] mentioned composite products are hard to recycle
- Open source mapping of resources as a technical opportunity
- The existence of 72,000 chemicals as a technical barrier

Typology or classifications for reuse ([Personal name 83], University of Leeds) - unpublished -

1. Action: the physic-mechanical role of the component in its previous deployment.
2. Material: The material from which the component is made and strength grade for the structural materials.
3. Deployment: The structural from or class in which the component was previously used.
4. Exposure: The environmental conditions to which the component has been subjected, associated with quantifications (e.g. weather records, detail of chemical environments, Eurocode EN1992 exposure classed) where appropriate.
5. Loading: The loading history of the component.
6. Recovery: The methods used to recover the component.
7. Residual: The structural and functional properties of the component remaining.
8. Connections: The capacity of the component to be connected to other structure and/or functional components or artefacts.
9. Availability: Details of when and where a component is found and quantity.
10. Generation: The number of times the component has been reused whether the proposed new use would represent the same function or cycling/cascading.

03 May 2017
Code: QA_19
Subject: Meeting no. 3 with [Personal name 24]

Comments he made on my [Company name 29] waste destinations chart:

Agriculture? What does that mean precisely

Could be good to calculate movement of vehicles and compare to the case If waste sorted onsite and sent directly to intermediary
What is cost difference of separating on site?

SKA is not looking at some of the fit-out waste streams (plastic, fines, glass)

When I call the intermediaries I could say something like: on behalf of UCL, we’re trying to improve our sustainability providing feedback to the Estates… to see if we’re meeting our waste targets

Other stuff:

Should check guidelines for PLATE paper

I thought I should ask [Personal name 78] what kind of report they get from [Company name 29]

Fit-out projects:

IoE -> starting June -They did a pre-refurbishment audit -[Personal name 24] wrote to [Personal name 9], Ben Croxford says wait till Friday, if not, chase the audit report via [Personal name 2] ([personal email])

TP PhD Project (Torrington) -> write them, see the site ([Personal name 77], <[personal email]>)

High tech lab -> [Personal name 24] has meeting on that this week, will tell me if there will be strip-out -they’re using SKA HE

05 June 2017
Code: QA_20
Subject: Meeting no. 3 with [Personal name 24]

[Personal name 24]’s thoughts:

Having to recycle based on a target percentage not the best way to go maybe

The system (as I expose it) has space for fraud, there could be fraud going on

Check cradle to cradle products, how they manage to go round the disposal issue

Other issues:

We discusses a bit the pre-refurbishment audit carried out by Sykes for IOE fit-out. -I said it’s quite bad

[Personal name 24] mentioned the Central House fit-out project, probably taking place during July and August

He said to send another email to [Personal name 77] about Torrington Place -[Personal name 24] says they should (but they don’t have to) help as ULC is the client

22 July 2017
Code: QA_21
Subject: Meeting with [Personal name 24] and [Personal name 9]

[Personal name 9] was there as he wanted to ask my opinion about the following:
BREEAM asks for 11.1 tonnes of waste/100m² GFA and fit-out contractors say they wouldn’t commit below 15, while Ben Croxford says the average at UCL fit-outs is 20-30.

I sent Ben Croxford the CRW Refurbishment Waste Benchmarking report I have.

Ben Croxford mentions that using tonnes/£k is subjective as you could use very expensive materials.

Ben Croxford mentioned ‘Warpit’ > an online portal to share used stuff (resource redistribution network), mainly for office furniture

05 October 2017
Code: QA_22
Subject: Meeting with [Personal name 18] (UCL Estates Strategy Manager)

[Personal name 18] > 50s, whitish hair and beard, glasses, kind person

[Personal name 18] was first contacted by [Personal name 20] when I asked [Personal name 20] about pre-refurbishment audit for Central House. [Personal name 24] also contacted [Personal name 18] asking about where furniture at Central House had been taken. [Personal name 18] mentioned he’d like to have a meeting with me. I sent him a reminding email each week; in the third week I asked [Personal name 24] to remind [Personal name 18] about our meeting, so [Personal name 18] sent me an email right away. We had the meeting today at room 303 in Bidborough House. I had to run a bit and arrived sweaty, [Personal name 18] was already waiting.

Where does UCL store furniture?

Before

UCL used to store most furniture at Hampstead Road, but the building is already demolished, why?

> the building is within the HS2-Euston reconstruction site, including two other former UCL buildings: The Podium and Wolfson House

> The Podium used to be where UCL [Company name 22] is located. Now they’re planning to move [Company name 22] to St Pauls (Le Grande).

Present

Currently, there is some storage space in Gospel Oak (near Hampstead Heath), but most storage space is in Clare Hall*

*Clare Hall: Blanche Ln, Potter Bar, EN6 3LD (by M25) -this site was originally planned to be uses as laboratory and office space, according to UCL Finance Committee, 2016 https://www.ucl.ac.uk/srs/governance-and-committees/committees/fc/minutes/1516/fc-290216.pdf

There are approximately 1600 pieces of furniture stored

They want to repurpose this furniture as it entails 10%-20% of cost of buying new

> The project entails to do an inventory of what furniture or whatever items are stored in UCL premises. The possible outcomes include:
• Donating
• Keep some for UCL’s fit-out projects
• Sell in situ > for instance, furniture can be kept at The Podium building to be reused by the new tenant
• *In general, selling is not an option as the action of collecting the furniture pays off for the furniture price, so it is a mutual favour

Future

Carry out the project mentioned above

They want to keep storage space to the minimum and not pay for storage

About Central House project

All furniture (workstations, chairs, lockers) were palletised and taken to Clare Hall

Bentham House (Law studies) will get refurbished and use some of this furniture

About Pre-refurbishment Audit/Inventory

[Personal name 18] says this is not normally done at UCL. They are more focused on the new stuff they will put in the refurbished space than what to do with the old stuff  -He says [Personal name 24] should know about this

> an exception is the case where the landlord demand to keep fittings/fixtures in place, so they have to either retain the stuff or store it to put it back before handing the space back to the landlord

About Reuse scenario

[Personal name 18] says is a matter of cost-benefit

> Factors to be consider are:
  • Storage cost
  • Maintenance cost (if item may deteriorate while stored)
  • Compatibility (e.g. in electrical components)
  • Cost/time of de-installing
  • Cost/time of recording the whole process

> It might be more cost effective to give away and buy new

I asked how I could find out the estimate cost of storing stuff at UCL, by weight or volume
> he asked me to email him about this and he’ll forward the enquiry to the corresponding person

To ask [Personal name 18] in the next email:
What is the estimate cost of storing furniture or other items at UCL? This figure could be calculated for a yearly period and for a given weight or volume of the stored items (e.g. £X per year per tonne stored -or- £X per year per m$^3$ stored).

How much furniture and other items are stored at Claire Hall?

10 October 2017
Code: QA_23
Subject: Meeting no. 4 with [Personal name 24]

We started talking about my flat situation and then went on to some ideas I’ve been thinking about – the Relative Reuse Cost (RRC) at UCL

UCL has another storage space called Silver Town (near ExceL)

I mentioned about Claire Hall and [Personal name 24] knows it, says it started as laboratory spaces but is sub-utilised.

I showed him my first proposal for an equation on RRC

He liked the idea and proposed that it would be good to consider not only pounds but also environmental costs (e.g. CO2 emissions)

> on the Reuse side this would include transport back and forth to storage
> on the Replacement side this would include transport and production of new item

[Personal name 24] raised the question of how to consider the new item as it could be a certified, sustainable, recyclable product or not. I think the new item to be considered should be the same as the old one.

He suggests to include the remaining lifespan as a factor… it’s not the same a reused item that will provide service for 2 years than a new one lasting 5 years. >this thinking about environmental costs but I’m realising it also affects monetary costs.

[Personal name 24] thinks it would be great to come up with something like:

- after transporting the reusable items 5 miles, it’s not worth the effort (money-wise or carbon-wise)
- If you want to save money or carbon emissions, you need a storage facility X km around, or you could store the items up to X months before you start losing money.
- How long can you store it for or how far can you transport it, so it’s cost-effective

About logistics at UCL

[Personal name 24] mentioned the company [Company name 52] -he says they take care of some transporting of UCL furniture, but he’s unsure if they have their own storage or whether they manage UCL’s storage or not.

About Central House

[Personal name 28] (UCL) might be able to tell me how much furniture was taken away from site.
About Torrington place and some general ideas

One of the rooms at Torrington Place fit-out was untouched as it was refurbished in 2014. When upper management saw this, the felt it would be better to refurbish the room equally to the surrounding rooms. [Personal name 24] argued that the current seating couldn’t be reused and it would be a waste of time.

In this case (as many more) aesthetics has overruled sustainability

He suggests it would be good to monitor what happens with the furniture in this case.

I mentioned what [Personal name 18] said about UCL only caring about the new incoming items and disregard the old outgoing items

[Personal name 24] mentions what he thinks is wrong is that each refurbishment project at UCL is isolated and just looking after itself

To do:

[Personal name 28] (UCL) about quantities and destinies of furniture at Central House

[Company name 52] about transport and storage costs at UCL

26 October 2017

Code: QA_24

Subject: Meeting with [Personal name 50] ([Company name 52])

[Personal name 24] has put me in contact with [Personal name 50]. [Personal name 24] says this company is in charge of logistics at UCL. Namely, they might be the ones that transport and store the furniture from UCL fit-outs. [Personal name 24] sent an email to [Personal name 50] introducing me -he didn’t reply so I sent an email thanking [Personal name 24] and asking [Personal name 50] for a meeting and he replied right away saying I can drop by his office after giving him a call.

Personal details:

[Personal name 50] [persona email]
Senior Logistics Manager

His desk is at: [Company address]
Mobile: [Company phone number]

Company details:

[Company name 52]

[Company website]

From their website: They deal with logistics and security. In logistics […] management fields such as transport, storage, material movement and people flow.

They have seven addresses, the one that could be relevant for my project is:

London Construction Consolidation Centre

Unit 7 Thames Rd
Silvertown, E16 2EZ
Issues to discuss:

1. What is the role of [Company name 52] at UCL?
2. How long have you worked for UCL?
3. Are they in charge of transporting AND storing items like furniture?
4. How is this process during a refurbishment?  e.g. >
   - UCL calls you to come collect the stuff at site previous or during a refurbishment
   - You collect using a cage wagon?
   - You take it to your storage site in Silvertown
   - When the item is needed again you transport it back to site
5. I suppose you collect stuff from many clients at Silvertown, how big is this storage space?
6. Can you estimate how much it costs for UCL or for WJ to storage stuff, per tonne or m3?
7. How much it costs to transport stuff, per tonne or m3?

From our chat at on 26-10-2017 @15:00:

WJ only transports and stores UCL stuff that is palletised.

This mainly implies construction supplies that need to be stored as UCL buys them in bulk (to get better prices) but don’t use them all right away > e.g. bricks, plasterboard, light fittings

Generally, these items are new. However, MW mentioned a case of stone slabs being stored for the new student centre. These slabs are heritage and were located on the same site.

When I asked if [Company name 52] could store reusable items, [Personal name 50] said yes, they can store and transport anything. However, according to their own regulations, they can only deal with palletised items > so one pallet goes in and one pallet goes out > e.g. they cannot open the pallets and carry a specific amount of items

The cost charged to UCL for storing is £6 per pallet, which is approximate to one square meter.

Usually, pallets cannot be stacked, so square meter is a more relevant parameter than cubic meter.

Transport is included in the contract signed with UCL. [Personal name 50] says they approximate fee they charge other clients is between £200-£500 per load, depending on the size of the vehicle.

The storage site is Silvertown (E16 2EZ) [which is about 12 km away from UCL]. WJ has three warehouse here where they store stuff from many clients. [Personal name 50] didn’t know the size of the warehouse but gave some contacts to enquiry.

MW also gave me:

22. The LCC Terms and Conditions
23. The LCC Contractor Information Pack >here there are more detailed figures for the fees of transporting

At the end, I mentioned I’m looking to why UCL does not reuse more building components. [Personal name 50] says:

24. At UCL, fit-out/refurbishment projects don’t talk to each other >Project Managers don’t talk to each other

25. UCL stores something for 18 months and then totally forgets about it

26. Also, items such as light tubes can get damaged in transport

27. He also says it’s a matter of cost-benefit: Items such as light fittings or sockets need to be tested before re-installing -this could be more expensive than buying new

When I asked tonne-pallet equivalent, [Personal name 50] says 26t=14pallets, 18t=12, 7.5t=10 [I must check this]

15 November 2017
Code: QA_25
Subject: Meeting with [Personal name 28] (UCL Waste Manager)

We met at the breakout space at Bidborough House (11:00). [Personal name 28] was referred to me by [Personal name 79]. [Personal name 28] is around his 60s, wears glasses, longish grey hair/behard, somewhat tanned skin. He belongs to the UCL Sustainability Team but also to UCL Estates. He has been very kind in responding my emails and he showed interest to support me on finding indicators for the relative reuse cost at UCL.

I spoke a bit about my project and how I found many items that can be reused from UCL fit-outs.

[Personal name 28] says he mainly focuses on items such as furniture, equipment, laboratory equipment, benching rather than other building components.

Current pathways for furniture reuse at UCL

- In-house reuse -> UCL can store removed items (such as furniture or HVAC units) at their storage site and keep them for further reuse at subsequent UCL refurbishment projects.
  - [Personal name 28] says they produced a form in which UCL departments state what they will need (e.g. desks) for an upcoming fit-out
  - Estates check what they have in stock to see what second-hand items they can provide
  - [Personal name 28] says reusing can represent one tenth of buying new.

- [Company name 9]-Reyooz -> [Company name 9] lists the items through Reyooz website to find “re-users”. Re-users collect the items directly from the building site. This pathway has only been used since the last 6 months.
Reyooz seems to be a better fit when they have a substantial amount of material (by bulk)

[Personal name 28] mentioned the charity Movations -> they provide training to upskill people for repairing, this is related to Reyooz

- Warp it -> The former pathway is being used parallely with Warp it platform (which UCL has been using for a while now). Warp it is a peer-to-peer platform, so re-users in this case are normally other institutions. Items can either be collected by re-users or delivered to them by UCL’s porters (outsourced) at a cost.
  - Warp it is a better fit for individual items
- JPA reuse scheme -> JPA provides a reuse scheme for their furniture: JPA collects they products to be reused, disassemble and palletise them, and re-assemble and bring them back when required -> this has shown to be cost-effective for UCL

**UCL’s storage sites**

Owned by UCL

- Claire Hall -> this is the main one -G says it’s about 100m² and is located 10 miles away
  - As this building is owned, UCL does not incur in extra costs when storing stuff here. The costs of maintaining the building are the same regardless of how full it is.
  - From Google Maps-> postcode: EN6 3LD  
    Direct distance from Claire Hall to the entrance of Wilkins Main Building: 19.77 km (12.29 mi)

- Gospel Oak

Managed by contractor ([Company name 52])

- Silvertown -> Estates avoid using this site to store stuff that might be reused soon, as there are costs incurred in transportation and storage. The cost of storage is around £5 a pallet.
  - Postcode: E16 2EZ  
    Distance (to Wilkins Building): 12.39 km (7.70 mi)

**Recent major strip-outs at UCL**

The following UCL buildings haven been/are being demolished because of the HS2 project demands it. Estates aimed to salvage the building components found in these buildings.

- Hampstead Rd
- Wolfson House
- One Euston Square
- The Podium

The Podium: Estates are salvaging/reusing JPA furniture found here. This furniture is a modular system called *Intrigue* which can be adapted for further projects.
Hampstead Rd: large desks found here are being salvaged through [Company name 9]-Reyooz.

**Behavioural difficulties for reuse at UCL**

[Personal name 28] says it can be difficult to persuade departments to use second-hand furniture.

Departments have expectations for their building fit-outs and prefer new products rather than reused.

Estates are trying to encourage reuse by providing reused furniture (or other items) at no cost. If the department still wants new products they should finance these themselves.

One example of reluctance to reuse is the Law department at Bentham House, where they refuse to get reused furniture as they want to provide a high-end space.

An opposite situation is Bartlett Department at Here East where they are encouraged to get reused furniture as it will be used for heavy-duty practices.

**About other building components**

Carpet, Partitions, Ceiling/Floor tiles, Cabling -> these components might be more difficult to reuse as removing them without damage can be represent higher difficulty (also more time and money).

HVAC units -> maintenance for further reuse of HVAC units is currently performed by UCL Maintenance and Engineering team (which is an outsourced contractor). This units are stored at UCL to be reused in subsequent fit-out projects.

**Regarding the “Relative Reuse Cost”**

I asked an estimate of how long UCL can store items for (such as furniture) so that reusing is cost-effective -> [Personal name 28] says it would be approximately 3 months.

Storage at Claire Hall can be considered free for UCL.

Transport cost must include man hours -> [Personal name 28] mentioned the cost of a recent job: UCL’s porters charged £230+VAT for a van load (approximately 20-30 desks+chairs+pedestals). However, this job was charged as ‘non-business as usual’. UCL’s porters are outsourced but have in-house operation, so their contract normally covers transportation of stuff at no extra cost.

[Personal name 28] had a look at the equation I’m proposing as an indicator to show the relative reuse cost. [Personal name 28] says this could be useful and he can help me apply it for some study cases.

[Personal name 28] has ‘schedules of costs and lifespans’ that might be useful -[Personal name 28] says, however, that the lifespan of a product also depends on where it’s located: if the building space requires a refurbishment the components will be removed regardless of their remaining lifespan.

**Next steps:**

1. Compile the data required to apply the relative reuse cost indicator, namely:
For the reuse scenario ->

- Transportation/storage costs (if any)
- Estimated product lifespans
- Cost of maintenance/testing (if required)

For the replacement scenario ->

- Waste contractor’s fee for collecting the item (this cost is given by tonnes probably)
- Price of new product

2. Use the indicator for some of the building components found in UCL fit-out (e.g. workstations, electrical socket, light fitting).

3. Present findings.

**B.3 Codes generated for the qualitative analysis**

Table 0.2 presents the codes or categories that were defined during the interviews’ qualitative analysis performed in NVivo, in alphabetical order. The codes were defined to be able to allocate every comment or idea from the interviews into one (or more) specific keyword. The creation of codes started with a word count to see words (or concepts) that were mentioned most frequently; then codes were edited, and new ones were added, as required. Coding aimed to find out key aspects and problems in fit-outs that need to be addressed. The ‘references’ in the table relate to the number of times a code was touched upon during interviews while ‘sources’ indicate the number of interviews in which a certain code was mentioned. The analysis considers 28 interviews or personal communications (i.e. phone calls or emails).
Table 0.2: Codes used during the qualitative analysis of interviews, along with the number of references and sources.

<table>
<thead>
<tr>
<th>Code/Category</th>
<th>References</th>
<th>Sources</th>
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<td>Definitions</td>
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Appendices

B.4 Example of references included in each code
As seen below, data contained in the files (personal interviews of communications) presented in section B.2 is broken down into different codes (presented in subsection B.3). Therefore, each code collates fragments of different files and each of these referenced files is called a reference. An example is given below for the case of code ‘Barriers of reuse’, which contains eight references. Several fragments contained in each code are used throughout the thesis, along with the corresponding citation stating the stakeholder actor that provided such information and the specific date.

<Files\2016 07  CircEL Workshop> - § 1 reference coded [12.19% Coverage]
Reference 1 - 12.19% Coverage

- Logistics for this purpose is costly, carbon intensive, and might also be complicated.
- Wood building components are not standardised, so it is difficult to reuse them in subsequent projects.
- People generally perceive used products as low quality or out of fashion.

<Files\2016 09  Meeting no. 2 with [Personal name 24]> - § 1 reference coded [4.72% Coverage]
Reference 1 - 4.72% Coverage

Speaking about the Present findings – what are the barriers, is it the manufacturer?

<Files\2016 10  Questionnaire to Waste Contractor 1> - § 1 reference coded [6.23% Coverage]
Reference 1 - 6.23% Coverage

21. Which do you think are the main barriers for recycling and reuse in fit-out projects?

Quality of materials that come out, e.g. can reuse carpet for safe walk in construction sites… Space, if you have no space you cannot segregate…. Education on the guys on the site…. [I asked whose education he said] strip outs’ responsibility… If they, [Company name 29], did the strip out with BREEAM, they would do a pre-audit… If tables are good they would recommend to reuse (to the main contractor), or donate to charities, tables, carpet tiles, doors…

If they do the strip-out, the logistics, and the waste…. He would go to the strip out site and identify recyclables … if you have three companies with their own agendas is more difficult…. It’s a lot easier with only one company involved.

On the other hand, if you got two companies the responsibilities is half, you got two companies thinking on it; principal contractor has to be in charge on everything, so whatever is easier for them.
with fit outs its materials going in so reuse is very unlikely as products are purchased to be put in, so the focus with fit-outs should be on waste reduction initially.

Reference 2 - 3.93% Coverage

21. Which do you think are the main barriers for recycling and reuse in fit-out projects?
The initial approach, firstly the strip-out/fit-out firms strategy, their client's demands and the site (size, restrictions, noise, dust etc.). All of these determine the overall strategy at site. The good thing is that our customers are becoming more and more environmental aware and their clients are demanding much more environmental and sustainability proficiency.

Reference 1 - 3.11% Coverage

Barriers and incentives (which were broken down into Environmental, Economical, Social, and Technical):

Reference 1 - 4.30% Coverage

I mentioned what [Personal name 18] said about UCL only caring about the new incoming items and disregard the old outgoing items

Reference 2 - 4.23% Coverage

[Personal name 24] mentions what he thinks is wrong is that each refurbishment project at UCL is isolated and just looking after itself

Reference 1 - 10.64% Coverage

- At UCL, fit-out/refurbishment projects don’t talk to each other >Project Managers don’t talk to each other
UCL stores something for 18 months and then totally forgets about it

Also, items such as light tubes can get damaged in transport

He also says it’s a matter of cost-benefit: Items such as light fittings or sockets need to be tested before re-installing - this could be more expensive than buying new

Behavioural difficulties for reuse at UCL

G says it can be difficult to persuade departments to use second-hand furniture

Departments have expectations for their building fit-outs and prefer new products rather than reused.

Estates are trying to encourage reuse by providing reused furniture (or other items) at no cost. If the department still wants new products they should finance these themselves.

One example of reluctance to reuse is the Law department at Bentham House, where they refuse to get reused furniture as they want to provide a high-end space.

An opposite situation is Bartlett Department at Here East where they are encouraged to get reused furniture as it will be used for heavy-duty practices.

B.5 Identification of gaps in the thesis based on the qualitative analysis coding
Table 0.3 illustrates how codes from qualitative analysis were used, at some point of the PhD project, to assess what had been covered so far and what aspects (codes) needed to be addressed.
Table 0.3: Codes from qualitative analysis to assess what had been covered in the PhD project.

<table>
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<tr>
<th>Name</th>
<th>Refs</th>
<th>Sources</th>
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<th>Should create section in</th>
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<td>*will touch on this if I do RRC</td>
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<td>LIT and RES *if new proposed</td>
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<td>LIT: Closed-loop supply chains</td>
<td>*could also be in New Business models</td>
</tr>
<tr>
<td>Logistics</td>
<td>9</td>
<td>GLO</td>
<td>LIT: Reverse logistics and tb scheme</td>
<td>*should include UCL logistics</td>
</tr>
<tr>
<td>Main contractor</td>
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<tr>
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<td>MET / RES</td>
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<td>LIT: Business mod. and platforms...</td>
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<td>LIT: Business mod. and platforms...</td>
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<td>GLO</td>
<td>LIT: Waste Man / RES: Alternative...</td>
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<td>SKA Rating</td>
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<td>LIT: FO assessment methods</td>
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<td>Space adaptability</td>
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<td>LIT: Design for adaptability</td>
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<td>Supply chain</td>
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<td>GLO</td>
<td>RES: FO supply chain structure</td>
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<tr>
<td>Supply chain resilience</td>
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<td>GLO</td>
<td>DIS: ‘Supply chain structure’</td>
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<tr>
<td>Take-back scheme</td>
<td>2</td>
<td>GLO</td>
<td>LIT: Reverse logistics and tb scheme</td>
<td></td>
</tr>
<tr>
<td>Taxing</td>
<td>6</td>
<td>GLO</td>
<td>LIT: Waste management and recycli</td>
<td>DIS: ‘Taxation’ or ‘Drivers’</td>
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<td>9</td>
<td>GLO</td>
<td>RES: ‘UCL pathways for salvag...’</td>
<td></td>
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<tr>
<td>UCL reuse</td>
<td>7</td>
<td>GLO</td>
<td>RES: ‘UCL pathways for salvag...’</td>
<td></td>
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<tr>
<td>User behaviour</td>
<td>1</td>
<td>GLO</td>
<td>DIS: ‘User behaviour’</td>
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<tr>
<td>Waste</td>
<td>11</td>
<td>GLO</td>
<td>LIT: Waste management / RES</td>
<td></td>
</tr>
<tr>
<td>Waste segregation</td>
<td>4</td>
<td>GLO</td>
<td>RES: FO waste man. and recycling</td>
<td></td>
</tr>
<tr>
<td>Wood</td>
<td>4</td>
<td>GLO</td>
<td>RES: Common FO WS’s and their...</td>
<td></td>
</tr>
</tbody>
</table>
C Structured questionnaire to Waste Contractors

The following questionnaire was designed for Waste Contractors, and it was used (exactly as it is presented) for interviewing Waste Contractor 1. However, for Waste Contractor 2 a more flexible interview was conducted, based on this questionnaire, but emphasising specific types of questions, such as those related to the flows of materials (e.g. amounts of waste collected, downstream suppliers, destinations of wastes).

Questionnaire to Waste Contractor

Date: ________________________ Name: ________________________

Education: ________________________ Contact: ________________________

Company: ________________________ Position: ________________________

PROJECT BRIEF: The project “Circular Economy in Office Building Fit-outs” is carried out in the UCL Environmental Design and Engineering Institute, by the PhD student Miguel Casas and supervised by Dr Ben Croxford. The project aims to trace the paths of different waste streams throughout the supply chain involved in fit-out projects, in order to identify potential improvements regarding sustainability. We appreciate your collaboration; all information will be treated as confidential.

PLEASE ANSWER THE FOLLOWING QUESTIONS FROM YOUR OWN PERSPECTIVE AND EXPERIENCE:

1. What are your main roles in the company?

Click or tap here to enter text.

2. What percentage of the waste that your company collects comes from fit-out projects?

Click or tap here to enter text.

3. Is there a significant disparity in the waste management among different fit-out projects in the UK? Approximately what is the highest and the lowest landfill diversion rate for fit-out waste?

Click or tap here to enter text.

4. Do you think landfill tax is the main driver for landfill diversion?

Click or tap here to enter text.

5. How low would the landfill tax need to be to make landfilling the preferred option or how high would it need to be to avoid any landfilling in fit-out projects?
6. How would you rank the different waste treatment options according to cost (from lowest to highest)? (e.g. 1. Waste to energy, 2. Recycling, 3. Landfilling, 4. Reuse)

7. What percentage in average of the fit-out waste that your company collects gets recycled, reused, incinerated, and landfilled?

8. What are the types of waste that your company collects from fit-outs? Which of these are the most common?

9. What are the rates that your company charges for these different types of waste?

10. Could all of these types of waste get recycled or are there some of them that cannot be recycled?

11. How do you measure the waste coming from fit-out projects? (e.g. by weigh, volume, container, etc.)

12. How does your company manage the waste collected? (e.g. spreadsheets, data bases, etc.) Do you compare these records against the fit-out contractor’s waste management plan?

13. Does your company store the waste after collecting it or is it immediately delivered somewhere else? If waste is indeed stored, where does your company store it?

14. Does this waste generally get mixed with waste coming from different sources?

15. Does your company have the facilities to carry out the recycling of the collected waste?

16. Where does your company take the waste to be recycled and/or incinerated? What are the rates that the recycling facilities charge or pay for each type of waste?
17. Why do you consider waste contractors often do not carry out the recycling themselves, and recycling facilities do not perform the waste collection by themselves?

Click or tap here to enter text.

18. Do you know what the different waste types get recycled into in the recycling facilities? Could you provide some examples?

Click or tap here to enter text.

19. How do you consider strip-out contractors could contribute to a more efficient waste management? (e.g. more careful removal of building components, better waste sorting, etc.)

Click or tap here to enter text.

20. Who do you consider generally makes the decisions within the fit-out supply chain on how to manage the waste? Which roles within this supply chain have the greatest effect on waste management?

Click or tap here to enter text.

21. Which do you think are the main barriers for recycling and reuse in fit-out projects?

Click or tap here to enter text.

22. How do you think waste management in fit-out processes can be improved?

Click or tap here to enter text.

23. Which aspects of waste management do you consider should have further governmental regulations?

Click or tap here to enter text.
## D Observational diary

### D.1 Layout of observational diary

Table 0.4: Date, code and subject for entries of observational diary.

<table>
<thead>
<tr>
<th>Date</th>
<th>Code</th>
<th>Subject</th>
</tr>
</thead>
<tbody>
<tr>
<td>28 June 2016</td>
<td>WC0_01</td>
<td>Visit to [Company name 9] MRF</td>
</tr>
<tr>
<td>13 October 2016</td>
<td>WC0_02</td>
<td>Visit to [Company name 9] recycling and waste management (Leyton)</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Waste Contractor 1</strong></td>
</tr>
<tr>
<td>21 October 2016</td>
<td>WC1_01</td>
<td>Site visit to [Company name 29], Interview to [Personal name 3]</td>
</tr>
<tr>
<td>22 October 2016</td>
<td>WC1_02</td>
<td>Diagram depicting the process at [Company name 29] Transfer Site</td>
</tr>
<tr>
<td>23 October 2016</td>
<td>WC1_03</td>
<td>[Personal name 3] replied my email with the following</td>
</tr>
<tr>
<td>28 October 2016</td>
<td>WC1_04</td>
<td>[Personal name 3] called me (as I asked him via email)</td>
</tr>
<tr>
<td>08 November 2016</td>
<td>WC1_05</td>
<td>I called [Company name 28] and [Company name 13] ([Company name 29]'s downstream supplier)</td>
</tr>
<tr>
<td>05 June 2017</td>
<td>WC1_06</td>
<td>[Personal name 3] reply on [Company name 29] building components and waste streams</td>
</tr>
<tr>
<td>08 June 2017</td>
<td>WC1_07</td>
<td>Email sent to me by [Personal name 48] (Quality Manager), from [Company name 5] ([Company name 48])</td>
</tr>
<tr>
<td>09 June 2017</td>
<td>WC1_08</td>
<td>[Personal name 48] sent another mail on the next day as I asked another question</td>
</tr>
<tr>
<td>12 June 2017</td>
<td>WC1_09</td>
<td>[Company name 29] waste stream shares</td>
</tr>
<tr>
<td>13 June 2017</td>
<td>WC1_10</td>
<td>[Personal name 3] wrote (after I emailed to thank him)</td>
</tr>
<tr>
<td>15 June 2017</td>
<td>WC1_11</td>
<td>I contacted by phone some Waste Collectors (transfer sites) and Recycling Facilities</td>
</tr>
<tr>
<td>15 June 2017</td>
<td>WC1_12</td>
<td>First email communication with [Personal name 69] from [Company name 28]</td>
</tr>
<tr>
<td>16 June 2017</td>
<td>WC1_13</td>
<td>Second email communication with [Personal name 69] from [Company name 28]</td>
</tr>
<tr>
<td>19 June 2017</td>
<td>WC1_14</td>
<td>Third email communication with [Personal name 69] from [Company name 28]</td>
</tr>
<tr>
<td>20 June 2017</td>
<td>WC1_15</td>
<td>Fourth email communication with [Personal name 69] from [Company name 28]</td>
</tr>
<tr>
<td>03 July 2017</td>
<td>WC1_16</td>
<td>Ben Croxford’s phone conversation with [Company name 39] metal recycling</td>
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<tr>
<td></td>
<td></td>
<td><strong>Waste Contractor 2</strong></td>
</tr>
<tr>
<td>26 May 2017</td>
<td>WC2_01</td>
<td>Site visit to [Company name 27], meeting with [Personal name 46]</td>
</tr>
<tr>
<td>27 May 2017</td>
<td>WC2_02</td>
<td>I emailed asking a few questions in relation to our previous meeting</td>
</tr>
<tr>
<td>14 June 2017</td>
<td>WC2_03</td>
<td>[Personal name 46] shared [Company name 27]’s waste stream shares via email</td>
</tr>
<tr>
<td>19 June 2017</td>
<td>WC2_04</td>
<td>Email conversation with [Personal name 59] from [Company name 26]</td>
</tr>
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<td></td>
<td>Bank offices</td>
</tr>
<tr>
<td>04 July 2016</td>
<td>CS0_01</td>
<td>Meeting with [Personal name 35], [Company name 33]</td>
</tr>
<tr>
<td>26 September 2016</td>
<td>CS0_02</td>
<td>Preparing for Site visit 1, Bank offices</td>
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<tr>
<td>27 September 2016</td>
<td>CS0_03</td>
<td>Site visit 1, Bank offices</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>UKGBC offices</strong></td>
</tr>
<tr>
<td>Date</td>
<td>Code</td>
<td>Subject</td>
</tr>
<tr>
<td>------------------</td>
<td>---------</td>
<td>-------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>04 August 2016</td>
<td>CS1_01</td>
<td>Meeting with [Personal name 55] from [Company name 42], about fit-out at the Building Centre</td>
</tr>
<tr>
<td>14 October 2016</td>
<td>CS1_02</td>
<td>Meeting 2 with [Personal name 55], [Company name 42], about fit-out project in Building Centre (UKGBC)</td>
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</tbody>
</table>

**UCL Confucius Institute**

<table>
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<th>Subject</th>
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<tbody>
<tr>
<td>12 January 2016</td>
<td>CS2_01</td>
<td>Meeting about a fit-out at UCL</td>
</tr>
<tr>
<td>23 November 2016</td>
<td>CS2_02</td>
<td>SKA scoping for UCL Confucius project</td>
</tr>
<tr>
<td>08 December 2016</td>
<td>CS2_03</td>
<td>Site visit 1 -before fit-out</td>
</tr>
<tr>
<td>09 December 2016</td>
<td>CS2_04</td>
<td>Units detailed per floor</td>
</tr>
<tr>
<td>12 December 2016</td>
<td>CS2_05</td>
<td>Inventory spreadsheet</td>
</tr>
<tr>
<td>07 February 2017</td>
<td>CS2_06</td>
<td>Site visit 4 with [Personal name 66] and [Personal name 62]</td>
</tr>
<tr>
<td>27 March 2017</td>
<td>CS2_07</td>
<td>Site visit 5, alone</td>
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<tr>
<td>11 April 2017</td>
<td>CS2_08</td>
<td>Site visit 6, talked with [Personal name 78] at IoE</td>
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<tr>
<td>05 May 2017</td>
<td>CS2_09</td>
<td>Site visit 7, Confucius Institute</td>
</tr>
<tr>
<td>27 June 2017</td>
<td>CS2_10</td>
<td>Site visit 8, after fit-out</td>
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<tr>
<td>15 December 2017</td>
<td>CS2_11</td>
<td>Questions about waste collection to [Personal name 78]</td>
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**UCL Central House**

<table>
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<tr>
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<td>CS3_01</td>
<td>First meeting – Pre-start meeting / Design stage</td>
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<td>19 September 2017</td>
<td>CS3_02</td>
<td>Site visit 1 at Central House, pre-refurbishment audit</td>
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<td>25 October 2017</td>
<td>CS3_03</td>
<td>Central House site visit, Interview with Site Manager – [Personal name 21] ([Company name 33])</td>
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<tr>
<td>07 December 2017</td>
<td>CS3_04</td>
<td>Central House site visit, interview no. 2 with Site Manager [Personal name 21] ([Company name 33])</td>
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**Conduit Members’ Club**

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<tr>
<th>Date</th>
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<tbody>
<tr>
<td>21 March 2017</td>
<td>CS4_01</td>
<td>Site visit 1 to The Conduit (hotel/club)</td>
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<td>09 June 2017</td>
<td>CS4_02</td>
<td>Meeting at Conduit Project</td>
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<td>05 July 2017</td>
<td>CS4_03</td>
<td>Conduit project – Globechain Open Day 2</td>
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<td>24 July 2017</td>
<td>CS4_04</td>
<td>Meeting – Conduit project meeting 3 – Post open day</td>
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<td>19 September 2017</td>
<td>CS4_05</td>
<td>Site visit 2 – during strip-out, with [Personal name 57]</td>
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<tr>
<td>01 November 2017</td>
<td>CS4_06</td>
<td>Meeting with [Personal name 60] and [Personal name 52]</td>
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**Other fit-out case studies**

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<tr>
<th>Date</th>
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<tbody>
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<td>13 March 2016</td>
<td>CSX_01</td>
<td>Meeting with [Personal name 24] about UCL Here East 2</td>
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<tr>
<td>21 March 2016</td>
<td>CSX_02</td>
<td>Meeting with [Personal name 24] about upcoming fit-out projects at UCL</td>
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<tr>
<td>26 September 2016</td>
<td>CSX_03</td>
<td>SKA scoping session for Bloomsbury Theatre refurbishment</td>
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<td>11 November 2016</td>
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<td>Bloomsbury Theatre SKA scoping BETA</td>
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<td>15 November 2016</td>
<td>CSX_05</td>
<td>Bloomsbury pre-refurbishment site visit</td>
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<tr>
<td>23 May 2017</td>
<td>CSX_06</td>
<td>Institute of Education (IoE) fit-out</td>
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</tbody>
</table>

### D.2 Waste Contractor Case Studies

#### D.2.1 Waste Contractor 0

**Summary**

- Main contacts: [Personal name 8] ([personal email]), and [Personal name 19].
- 28-06-2016 -site visit 1, [Personal name 19] introduced some facts about the company, and [Personal name 8] [Personal name 8] showed me around the site.
• 13-10-2016 - site visit 2, [Personal name 8] [Personal name 8] gave me a second tour of the site, along with [Personal name 13] and [Personal name 4]; more detailed was given into the segregating process.

28 June 2016
Code: WC0_01
Subject: Visit to [Company name 9] MRF
Hosts: [Personal name 8] [Personal name 8] and [Personal name 19]

• [Company name 9] is a privately owned company; started in 1919
  o They’re just one step in the chain as they later give the materials to someone else to recycle or use them
  o They work regionally for London and southwest of UK
  o As for 2016 it has two facilities in west London (Bow) comprising about 16,500 sq m each
  o The attain 92% recycling with a speed with a rate of 120 tons p/hour (when machines are working)
  o They’ve just installed a 1 MW solar panel system
  o They got a new machine to separate paper by infrared technology which uses refractive indexes of materials
  o They have other machines for separating plastics they designed themselves

• Untreated wood gets recycled while bad one goes to energy (separated by hand)
• They work with plasterboard (along with British Gypsum). They take away the contamination in the plaster by human hand and with electromagnets (for metal particles) and then give the material to British Gypsum
• The process in general is as follows:
  1. Waste gets in (they measure the waste with a weighbridge on which the ingoing trucks stand; also the outgoing waste gets measured)
  2. Waste gets checked by the pickers
  3. Then they use the trummel to rotate the waste and fine materials fall through the gaps (<14mm)
  4. They use a cyclonic system in which heavy material goes down
  5. They use some kind of inclined band in which heavy goes down and light (as paper) goes up
  6. Infrared separation, determines what should remain on the band and what goes automatically thrown down to the sides

13 October 2016
Code: WC0_02
Subject: Visit to [Company name 9] recycling and waste management (Leyton)

[Personal name 8], [Personal name 13], [Personal name 4] and me, guided by site Manager ([Personal name 8]), It was rainy, [Personal name 8] bought us burgers, we had a chat at the lunch

They collect waste mainly from businesses ([Personal name 8] mentioned [Company name 53] and [Company name 54])
About 40% of incoming waste is collected by them, and 60% is brought by other collecting companies.

They charge about £100 per ton, while landfill charges about £120 per ton (including landfill tax).

In the facility no. 1 (the outdoors muddy one) they receive general waste.

In no. 2 (indoors one) they receive domestic/office waste.

They do not accept: hazardous, clinical, liquids, and tires and plasterboard. The two latter have legislations which require closed-loop recycling (British Gypsum is main plasterboard recycler, but only accepts their own).

The overall process at facility no. 1 is:

1. Waste goes to the Pickers station where there is a moving band and about four guys are hand-picking the following: metal, wood, bricks, and comingle (plastic, cardboard, paper).
2. The remaining waste goes to the trummel (massive rotating cylinder) where the soils and small particles, called the Fines, get filtered to the ground.
3. Whatever is left gets compressed and packed in cylinders (called Bails) and is sent to Holland go become waste to energy.
   - Hand-picked recyclables are sent to different recycling facilities. They don’t get glass since glass is normally separated by other people before sending the waste.
     - Wood is not separated by grade. Wood is generally sent to a specialised recycling facility called Connect in Dagenham.
     - When they receive construction waste, they don’t mount it on the Picker station, but they separate directly on the ground by Grabs (caterpillar machines).
   - They fill-up 36 curtain-side-trailers each week for waste to energy. Each trailer carries 25 tons (42 tons including trailer’s weight). They send the bails to Holland just because it’s cheaper.
   - The Fines are used for covering landfills every day or to back-fill holes (like in a golf course).

Facility no. 2 has a different process, they use pickers but also specialised machines to separate recyclables.

Random facts:

The containers are called Skips.

[Personal name 8] says (while driving with him and at lunch):

Moving waste around London costs about £100-£150 per load. Is more cost-effective to use large trailers.
In Waste to Energy facilities, only 25% is actually electricity output. Out of the 75% remaining, 80%-90% can be recovered as heat for district/water heating.

Showed us a website called ReYooz.com (beta testing), which is for business giving away stuff they don’t use. He says this is not Freecycle, as Freecycle is a peer to peer process.

Colin mentioned a web US web called Stuffstr, which keeps track of people’s belongings (how long they keep the stuff, how long item lasts) and sells this info to manufacturers.

D.2.2 Waste Contractor 1

Summary

- Main contact: [Personal name 3] ([personal email]), [Personal name 35] gave me his contact.
- 21-10-2016 -I visited the site and met him (and [Personal name 51]) on Friday at Barking. [Personal name 3] answered the Q&A and showed me around the site.
- 23-10-2016 -emailed [Personal name 3] asking about what waste gets recycled into, and about recycling facilities contacts.
- 26-10-2016 -[Personal name 3] replied me with some info about the first question, but none about the second, I wrote him back asking if I could call him for further questions
- 28-10-2016 -[Personal name 3] called me. I asked questions about which building components make up specific waste streams (as metal). Also asked about waste stream destinations.
- 08-11-2016 -I called [Company name 28] and was directed to a guy called [Personal name 67], asking about their process and what they do with the plasterboard.
- 08-11-2016 -I called [Company name 13] -they also told me they send the material to someone else to recycle.
- 14-11-2016 -sent [Personal name 3] and email with a chart to complete on the waste streams destinations
- 12-05-2017 -[Personal name 3] emailed me and sent back the waste streams destinations chart, I replied asking some more specific questions about building components and waste streams.
- 03-06-2017 -I emailed him asking for share of collected waste streams, sent him a new spreadsheet.
- 05-06-2017 -[Personal name 3] replied answering questions about building components and waste streams >see report.
- 09-06-2017 -[Personal name 3] wrote me asking if I want one year percentages of waste streams for all waste (N/A just for fit-out waste) or fit-out waste reports (but these later are comprised largely of mixed waste so he says wouldn’t be useful) -I replied opting for the first option.
- 12-06-2017 -I sent an email to the recycling facilities referred to by [Company name 29]: [Company name 6], [Company name 13], [Company name 28], [Company name 34], [Company name 47], [Company name 40], [Company name 39], [Company name 51], and a web message to [Company name 46].
- 13-06-2017 -I wrote to [Company name 55] regarding Insulation -They replied right away saying they don’t deal with Insulation but provided the following link https://www.mrw.co.uk/ (Material World Recycling).
Appendices

- 15-06-2017 - I phoned [Company name 28] and [Company name 13]. The few info they provided is on a report and on the Suppliers Details spreadsheet.
- 15-06-2017 - While looking for Insulation recycling facilities I ran into the website <http://www.wastebook.org/> which provides recycling facilities for a list of waste streams. From here I phoned the following within the EPS list: EPS Recycling International and Cordek. As well I sent an email to the latter plus Kay-Metzeler Ltd.
- 19-06-2017 - [Personal name 69] ([Company name 28]) replied saying they don’t deal with [Company name 29]’s waste since November 2016. I asked her what they do with plasterboard anyways, she replied back saying all of it goes to British Gypsum or Knauf - I asked if this is true for all of the plasterboard.
- 20-06-2017 - [Personal name 69] ([Company name 28]) replied saying that Gypsum gets indeed sent to other uses such has cement manufacture and agriculture but in minimal scale - I replied asking if she knows the average percentages.
- 03-07-2017 - Ben Croxford phoned [Company name 39], he was directed to the site manager [Personal name 53] - not much information was given - Ben Croxford sent me an email with this which I have in the respective folder.

21 October 2016
Code: WC1_01
Subject: Site visit to [Company name 29], Interview to [Personal name 3]

My notes after interview:

Company started as a brick company. The site I went to is 2.5 acres long (I think)

This MRF, all hand pickers, 16 guys… machines will make these unemployed

Conveyor belt goes round, not just once

They get cardboard (packaging), correx (plastic), timber, metal, plasterboard (sent to [Company name 28]), hardcore (bricks, rubble, concrete)

[Company name 28], started as a plasterboard recycling company… there are five grades of plasterboard, thin, thicker… this company then takes and sells plasterboard (after sorting it) to British Gypsum or Knauf.

British gypsum or Knauf will only go the site to take their own, but they can receive others’ if it’s good grade.

If plasterboard is not good enough to go to manufacturer, it will go to another use, cat litter for instance, if they don’t get the grade.

Mid uk have 8 Air craft carriers in Grantham

In [Company name 29], after all is segregated, [through the trammel and the picking station], it’s called residual waste, A says it has no EWC code…. This goes to landfill (M said about 3-5% of total).

Ask him for:

- Didn’t show me machine that extracts mercury (another visit sometime)
- A said they audit rec facilities and they it’s duty of care to know what happens with the waste at the end: could he tell me more about this?
- Recycling facilities contacts
- Waste recycling report example

Questions to add next time:

What percentage of the waste you get is segregated and what percentage is mixed waste?

[Personal name 51] and [Personal name 3] showed me around the site, the following came up:

Metal, gets on a ship (Thames is right there on the back) and is taken to Germany, Spain, or India, wherever they give more money.

Plasterboard: [Company name 28]

Cardboard, plastics: [Company name 13], just across the road

Timber: C grade goes to Belgium to get turned into particleboard

A,B grade becomes animal bedding, but they don’t get so much of this.

When pallets are added in the mix they make a better C grade to be recycled into particleboard

They reuse pallets in good state for their own strip-out projects.

Plywood (good one) gets separated and then donated, given away (free collection for anyone), or reused by them.

Glass: segregated glass goes to [Company name 5], they think it then becomes aggregate or bottles.

The one that is too fine, gets thrown into the fines.

Fit-out projects sometimes reuse glass on-site.

Fines: are sent to another company that furthers sort it. Good fines can be used for landfill capping.

They work Monday to Friday from 8 to 6, and Saturday half they, although they have a 24/7 license.

Other notes:

Company looks tidy and organised, [Personal name 3] and they guy next to him had their desks very tidy. Toilets are clean. [Personal name 3] is very nice, maybe younger than me, shorter than me, with glasses and with some pimps on the face, moves the eyebrows similarly to Isabel when talking. He didn’t seem to know that much but is happy to help. Mark seemed a little arrogant at the beginning but then became very helpful and answered all my questions.

They have the timber pile outside (I suppose because they get many deliveries of it so it’s easier to access), they would do the shredding right next to the pile; mixed waste pile is inside the building (right in the middle); plasterboard is next to it in a corner near the entrance;
fines are to the left of plasterboard (2 piles of fines); metals have two piles on the back of the building (where it gets boarded on the ship).

The overall process is:

1. Waste gets in
   1a. Segregated waste goes directly to the respective pile
   1b. Mixed waste goes into the mixed waste pile
2. Mixed waste goes to the trammel to separate the fines.
   2a. Fines are sent to another site
3. Waste goes to picking station
4. Each segregated waste stream goes to respective recycling facility
   4a. Timber gets shredded before sending it.
5. Residual waste goes to landfill.

22 October 2016
Code: WC1_02
Subject: Diagram depicting the process at [Company name 29] Transfer Site

This diagram was constructed based on information provided in the interview with [Personal name 3]. The diagram shows the process for sorting waste at the MRF or Transfer Site.
23 October 2016
Code: WC1_03
Subject: [Personal name 3] replied my email with the following

- **Plasterboard** ([Company name 28]) [Company name 28] > Cement manufacture 65%, Plasterboard manufacture 15%, Agriculture/ Horticulture 6%, Mushroom compost 14%.
- **Cardboard, plastics** (Edwards) [Company name 13] > C/B Redistributed back to the paper mills for reconstitution back primarily as card. Plastic reconstituted back into a lower quality bags principally carrier bags.
- **Glass** ([Company name 5]) [Company name 5] Recycling > used in glass polymers, paving stones, buildings and fluorescent tubes
- **Metal** (*outside UK*) [Company name 39] > Ferrous metals are shipped via ship around the world to various re-processors for reconstitution back into metal-based products, Batteries and ferrous metals are reprocessed and then composite materials re-constituted back into various manufacturing industries.
- **Timber** (*Belgium*) [Company name 61] Belgium > Biomass energy generation 30% and Board Making 70%. Pallets reused in original state on [Company name 29] logistics project.
- **Carpet** > Carpet Tiles loaded onto pallets and removed from site, then reused on projects or sent for charitable reuse.
- **Raised floor tiles**: Processed at [Company name 29] where metal is separated from the timber. The timber is then sent to Unilin Belgium and the metal is sent to [Company name 39].
- **Ceiling tiles**: Take-Back-Scheme with Armstrong Ceiling Tiles used where possible.

28 October 2016  
Code: WC1_04  
Subject: [Personal name 3] called me (as I asked him via email)

He gave me the following further information:

**Metal**: made up of MnE, they don’t get much lighting fittings > people installing new fittings generally take the old ones, the might reuse them or maybe not, no further info. > it is sent to [Company name 39] which is in the UK.

**Timber**: made up of pallets, scaffolding, plywood, furniture or partitions stud.

**Carpet**: they don’t get much > taken to a charity called Kenya Aid or reused to protect new installed flooring while fit-out works (to avoid people walking on the new floor)

**Ceiling tiles**: they don’t get much (probably because these have a take-back scheme). > they remove the paper layer and then crush the tile (he doesn’t know the material).

Armstrong ceilings take these when they go on site to install new ceiling tiles.

**Hardcore**: crushed and used for aggregates mainly

**Fines**: Landfill capping (he actually did not give me further information)

**Insulation**: they don’t get that much. He didn’t seem very sure about this but told me that sometimes is used as sound insulation as cannot be used as thermal insulation anymore.

**Cardboard**: comes from packaging

08 November 2016  
Code: WC1_05  
Subject: I called [Company name 28] and [Company name 13] ([Company name 29]’s downstream supplier)

I called UK Mid Recycling on the number 08003101815

They directed me to a guy called [Personal name 67]

I asked him if the figures that [Personal name 3] gave me were right, he said they sound right:

- 65% cement production
- 15% plasterboard production
- 14% mushroom compost
- 6% Agriculture/Horticulture

They don’t actually do the recycling, what they do is Screen and Grade the material into different particle sizes

- The fines size for plasterboard is <1.2mm
For cement production they send it to Cemex or other manufacturers in the UK, and some abroad

For plasterboard manufacture they send it to British Gypsum or Knauf

- In [Company name 28] they make sure the plaster is good quality for this by their code and control team using the TAS? 199 Standard
- [Personal name 67] didn’t know what the actual criteria was for this standard

For mushroom compost and agriculture they send it to farmers in the UK

I asked if they recycle on-site any material, such as plastic, glass or metal. He said no, what they do is prepare the material to be used in a manufacture process.

They turn general waste into fuel

He mentioned they get carpet, this is also turned into fuel

I also called [Company name 13], and they also told me they send the material to someone else to recycle.

05 June 2017
Code: WC1_06
Subject: [Personal name 3] reply on [Company name 29] building components and waste streams

On 12-05-2017 I emailed [Personal name 3], as he’d just replied and filled out the waste streams destinations spreadsheet -In this subsequent email I asked him about Building components and Waste streams

[Personal name 3] replied the following:

---------------------------------------------------------------------------------------------------

BUILDING COMPONENTS:

Are these (sometimes) broken into different waste streams or treated as inseparable components?

- **Electrical cable**: metal OR just WEEE > treated as metal
- **Electrical socket**: [plastic & metal] OR just WEEE > separated into plastic and metal
- **Carpet**: [textile & plastic] OR just carpet > just carpet

WASTE STREAMS:

Are these included within a waste category (e.g. glass/hardcore) or correspond to a different waste stream?

- **Ceramic** (sink/toilet/wall pane/floor tiles) > goes through the same recycling process as Hardcore
- **Fibreglass** > (ductwork/ceiling tiles)
- **Marble** (hard flooring) > goes through the same recycling process as Hardcore
- **Glass mineral wool** (insulation/ceiling tiles) > Take back scheme with manufacturer or broken down to separate the paper from the tile and treated as paper
- **Rock mineral wool** (insulation) > can be reused as sound insulation
- **Stone** (hard wall covering) > goes through the same recycling process as Hardcore
Are these treated as the same waste stream?

- Cellulose (insulation/some ceiling tiles), Paper. > Paper ceiling tiles are
- MDF, Wood, Woodchip > yes
- Phenolic foam (insulation), Polystyrene, Polyurethane (insulation) > No, treated indi-
  vidually
- PVC (ductwork/window frame), Hard plastics > They go to the same end user to be
  processed.

08 June 2017
Code: WC1_07
Subject: Email sent to me by [Personal name 48] (Quality Manager), from [Company
name 5] ([Company name 48])

Miguel

Windows, partitions, doors, ceiling panels really any type or architectural glass is collected
together and termed as “mixed plate” within the glass recycling industry. These different
types of glass are collected together, whether the glass is toughened, laminated, fire resistant
laminated or standard plate glass. The only type of types of glass not collected for recycling
are what we term glass ceramics, this is glass with a different chemical composition and melting point to those mentioned, the volume and usage of this material is however very low due
to its cost.

Once collected the mixed plate is transferred to one of our depots in either Tilbury or Bir-
mingham or direct to head office in Pontefract. Here the material is stored with other plate
glass such as car windscreens before been shredded to reduce the particles size and free the
PVB from the laminated glass. (PVB is the clear plastic interlayer sandwiched between two
pieces of glass such as in car windscreens or safety glass.

Once shredded the very fine glass particles <4mm are crushed to remove shards and sold as
a recycled aggregate for use in the manufacture of building blocks.

The material >4mm is then processed through our plant, here optical sorting equipment
detects and ejects non glass such as stones, plastic, metal objects, (items like aluminium win-
dow bars from double glazed units, metal fixings from glass partitions, stones from handling
and movement on the demolition site).

Once the material is processed it undergoes QC controls to ensure that it meets customer
requirements. Post inspection the material is supplied in bulk loads of 29 tonnes to customers
who produce glass packaging (bottles and jars) & glass wool (loft insulation). These markets
can accept the quality of the material processed from mixed plate, none of the mixed plate
collected is reused into new plate glass manufacture as this has a much higher quality re-
quirement.

The types of glass collected from glaziers and double glazed manufactures (off cuts and bro-
ken glass from the manufacturing process) can be processed to this very high standard and
reused in plate glass manufacturer.
The majority of the non glass components are separated and used in different ways. The aluminium window bars are sold to a company who remove the rubber then recycle the aluminium, other metals are sold for recycling, and the PVB interlayer can be used as RDF (refuse derived fuel) or in cement manufacture.

An approximate split of the material received to the material leaving our site is:

- 88% re-melted into new glass products
- 7% used as recycled aggregate
- 1% metals for recycling
- 4% PVB for RDF or Cement manufacturer

The majority of glass manufactures in the UK are based along the M62 corridor, the exceptions are O-I in Harlow and the O-I & Aradgh glass manufacturers in Scotland. The mixed plate we collect and process is predominantly supplied to glass manufacturers in Yorkshire where it’s added to the batch materials and re-melted to form new bottle and jars.

Historically some of this processed mixed plate has been shipped to other glass manufacturers across Europe including Spain and Portugal.

My notes:

This is very useful and much detail is provided. I must email him back and ask the following:

- only 7% for aggregates?
- where are aggregates sent to for the manufacturing of building blocks?

09 June 2017
Code: WC1_08
Subject: [Personal name 48] sent another mail on the next day as I asked another question

Miguel

Glad I can help.

There are a number of block manufacturers within a 30 mile radius of our operation near Pontefract who we supply with recycled glass aggregate. There are other block manufacturers throughout the UK some of which will use recycled glass aggregate but are not served by ourselves.

The technology and practices that we operate allow us to achieve a high % yield to re-melt and ensure a minimal amount of material is used for alternative uses such as aggregate.
We strive to ensure that as much material as possible is used for re-melt within the UK opposed to aggregate and export. This approach to closed loop recycling helps to protect the environment whilst supporting our own business and the UK glass manufacturing industry.

12 June 2017
Code: WC1_09
Subject: [Company name 29] waste stream shares

After insisting for a long time, these are the figures that [Personal name 3] has provided in relation to [Company name 29] waste streams shares:

Hi Miguel,

I have taken figures from a period in 2016 and then used this to get an estimate for a 12month period.

This is done by weight not volume and is for the materials that have come into our weighbridge from sites and outside tippers so as discussed is not specific to fit-out only projects and includes large amounts of ‘mixed waste’ due to it being the most commonly requested EWC code for collections of materials.

<table>
<thead>
<tr>
<th>Material</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plasterboard</td>
<td>5%</td>
</tr>
<tr>
<td>Wood</td>
<td>13%</td>
</tr>
<tr>
<td>Mixed waste</td>
<td>74%</td>
</tr>
<tr>
<td>Raised access flooring</td>
<td>4%</td>
</tr>
<tr>
<td>Plastic</td>
<td>less than 1%</td>
</tr>
<tr>
<td>Textiles</td>
<td>less than 1%</td>
</tr>
<tr>
<td>Glass</td>
<td>less than 1%</td>
</tr>
<tr>
<td>Mixed packaging</td>
<td>less than 1%</td>
</tr>
<tr>
<td>Brick &amp; rubble</td>
<td>2%</td>
</tr>
<tr>
<td>Soil</td>
<td>less than 1%</td>
</tr>
<tr>
<td>Biodegradable waste</td>
<td>less than 1%</td>
</tr>
<tr>
<td>Insulation</td>
<td>less than 1%</td>
</tr>
<tr>
<td>Tyres</td>
<td>less than 1%</td>
</tr>
<tr>
<td>Metal</td>
<td>2%</td>
</tr>
</tbody>
</table>

As you can also see they have been put into the most basic waste streams.

Any queries please give me a call.
13 June 2017  
Code: WC1_10  
Subject: [Personal name 3] wrote (after I emailed to thank him)

Miguel,

Not a problem.

Please note that the segregated materials listed are the %’s of waste that come in segregated. The mixed waste would be further segregated by our recycling process.

15 June 2017  
Code: WC1_11  
Subject: I contacted by phone some Waste Collectors (transfer sites) and Recycling Facilities

1. Phoned [Company name 28] (about Gypsum and Insulation).
   - Admin phone number didn’t work so I tried Recycling phone number ([company phone])
   - A guy answered saying I should write to [Personal name 69], Sales Manager, ([personal email]) which I did.

2. Phoned [Company name 13] (about Paper and Plastic)
   - A guy (seemed very busy) answered on [company phone]
   - He says they are a transfer site and Paper is sent to King’s Lynn while Plastics are sent to different recycling centres in China.

As I was looking for Insulation recycling facilities I ran into the website http://www.waste-book.org/ which provides recycling facilities for a list of waste streams. From here I contacted the following within the EPS list:

**EPS Recycling International**

- I called them, I should call tomorrow in the morning to speak to the guy in charge of that

Tel 0207 457 5014  Fax 0207 457 5045

Email abarnets@bpf.co.uk  or  info@epsrecycling.org
Website www.eps.co.uk  or  www.epsrecycling.org/pages/intr.html

EPS Information Service, 6 Bath Place, Rivington Street, LONDON EC2A 3JE

The International EPS alliance is an industry federation comprising EUMEPS Packaging (Europe), AFPR (America), and AMEPS (Asia). Website details four main waste reduction options for EPS packaging - reduce, reuse, recycle and 'recover' (ie incinerate). It explains 4 ways of mechanically recycling EPS; how most recycling schemes work: compaction, collection, granulation, blending and extrusion; and report on life cycle analysis. Lists countries whose EPS Foam Packaging Associations have signed the International EPS Recycling Agreement, and states what this involves.
Cordek

- I called them, they told me to email them (sales@cordek.com)

Tel 01403 791717   Fax 01403 791718

Email aseaton@cordek.com  Website www.cordek.co.uk

Spring Copse Business Park, SLINFOLD, West Sussex RH13 9SZ

Contact  Alistare Seaton

Collects and processes EPS to manufacture moulded EPS block and sheet for construction industry. Reuses polystyrene as a filling for engineering products. Can only accept relatively small quantities of clean material from businesses in surrounding area.

Tusarora Ltd

Tel 01604 752355 Fax 01604 759024

Cornhill Close, Lodge Farm Industrial Estate, NORTHAMPTON NN5 7UB

Recover clean EPS, foamed PE and PP. Supply EPS and foamed PE and PP products.

Central Recycling Group

- I called them but apparently they ran out of business.
- It says on the website that they turn EPS into garden furniture (which matches what [Company name 29] says).

Kay-Metzeler Ltd

Tel 01245 342100  Fax 01245 342123

Brook Street, CHELMSFORD, Essex CM1 1UQ

Email eps-reception@kay-metzeler.co.uk  Website www.kay-metzeler.com

Collector and processor of EPS, for use in construction, furniture, packaging, scenery, sculpture, horticulture and agriculture. Accredited recycler, recycling own waste EPS and that of customers. Contaminated packaging such as fish boxes and mushroom containers can now be recycled. Manufactures new 'Kay-Cel' products such as flooring, cavity wall insulation, roofing, seeding and bedding trays for horticulture, packaging for fresh produce, screen printing and package design service for trays and boxes, 'safe-fall' blocks to reduce building site injuries, 'Claylite' to protect building foundations, and loadbearing blocks for landscaping. Claims EPS is more acceptable than packaging such as moulded paper pulp, in terms of air pollution, energy usage, water pollution, and global warming potential. Part of the British Vita group.

This is the speech I used when calling:
Good Afternoon,

My name is Miguel and I am conducting a PhD study at UCL in collaboration with UCL Estates in order to trace the paths of waste streams generated during UCL building fit-out projects. I have been referred to your company through [Company name 29] in relation to the waste stream of 'Gypsum (plasterboard)'. I am looking for information on the destinations of this waste stream, which would greatly help our study.

The following aspects are of particular interest:

* What are the final destinations of this waste stream (what it gets recycled into/used for).
* In what estimate percentages (e.g. 70% plasterboard manufacture, 20% moisture absorbent, etc.).
* How far away from London/the UK.

15 June 2017
Code: WC1_12
Subject: First email communication with [Personal name 69] from [Company name 28]

Dear [Personal name 69],

I hope this email finds you well.

I am conducting a PhD study at UCL in order to trace the paths of waste streams generated during UCL building fit-out projects. I’m copying [Personal name 24], UCL EHS Officer, as this study is a joint effort with UCL Estates. I have been referred to your company through [Company name 29] in relation to the waste streams of 'Gypsum (plasterboard)' and 'Insulation materials' in a smaller scale. I am looking for information on the destinations of these waste streams, which would greatly help our study.

The following aspects are of particular interest:

* What are the final destinations of this waste stream (what they get recycled into/used for).
* In what estimate percentages (e.g. for gypsum: 70% plasterboard manufacture, 20% moisture absorbent, etc.).
* How far away from London/the UK

Would it be possible for you to provide some support or kindly direct me to whom may be able provide some information?

I am thankful for your support.

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Hi Miguel

We supply a small amount to the cement industry and into agriculture but the majority does back into plasterboard.

Kind Regards

[Personal name 69] BSc (Hons)
Hi Miguel

We’ve not accepted any waste from [Company name 29] since November 2016. Could you check when this was relevant to please.

19 June 2017
Code: WC1_14
Subject: Third email communication with [Personal name 69] from [Company name 28]

Hi [Personal name 69],

Thank you very much for your response and your support

Regarding plasterboard, may I please ask you:

- Would you say all of the plasterboard you get goes to new plasterboard manufacture (even the lower grade)?

- Is none of the plasterboard sent for other uses, such as cement manufacture or agricultural purposes?

Many thanks for your kind support once more.

-----------------------------------

Hi Miguel

No problem!

The plasterboard is processed at our site in Lincolnshire. We extract the gypsum which is supplied to plasterboard manufacturers (British Gypsum at East Leake, Notts and Knauf at Immingham, North Lincs), where it is used in the manufacture of new plasterboard.

The paper is supplied to farmers as animal bedding.

I hope that helps.

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Hi [Personal name 69],

Thank you for your response.

The reference leading to [Company name 28] was provided during an office fit-out case study taking place during 2016.
Although the waste streams generated at UCL fit-outs are diverted into different MRFs/transfer sites, it would be certainly useful for this study to gain some insight regarding the tendencies of the waste streams that arrive at your company.

Hopefully you can provide some information that can greatly help this study. We are very thankful for your support.

20 June 2017
Code: WC1_15
Subject: Fourth email communication with [Personal name 69] from [Company name 28]

My notes:

Not much new info provided. She confirms plasterboard goes to plasterboard manufacture (mostly), to cement manufacture and agriculture.

Hi Miguel

A very rough guide is 80% plasterboard, 10% cement, 10% agriculture.

-----------------------------------

Hi [Personal name 69],

Thank you for your response.

Last question (I promise):
- Do you have an estimated average of the percentage of plasterboard that goes to 1) new plasterboard manufacture, 2) cement manufacture, 3) agricultural purposes, 4) other.

You've been very kind and helpful.

03 July 2017
Code: WC1_16
Subject: Ben Croxford’s phone conversation with [Company name 39] metal recycling

Ben Croxford called [Company name 39], after reviewing the information they have on their website. Ben was directed to the Site Manager (see details below). At the end Ben Croxford said it is indeed tricky getting information from them.

[Personal name 53] from
S-Norton
Barking Department

This company mainly do onward shipping
So they compress metals and ship to other places

They use weighbridge ticket receipt
Appendices

They use EWC codes and record where waste comes from whole company does annual reporting to Environment agency (EA)

total ferrous / non-ferrous splits by mass

EA report from regional sources

All metal gets shipped abroad (they couldn’t provide detail)

Destination entirely based on price offered (commercially sensitive information)

Very small Aluminium at Barking most of it goes to Manchester site

D.2.3 Waste Contractor 2

Summary

- Main contact: [Personal name 46] ([personal email]); [Personal name 35] gave me his contact.
- 12-10-2016 - I sent Q&A file to [Personal name 46], he hasn’t replied.
- 19-10-2016 - [Personal name 46] sent me an email saying he’d reply tomorrow.
- 26-10-2016 - wrote [Personal name 46] saying we could do the Q&A in person and asked him about different waste streams flows.
- 01-11-2016 - [Personal name 46] wrote me and sent Q&A. In the part regarding waste streams destinations he said it’d require an essay to explain the whole process.
- 02-11-2016 - I emailed [Personal name 46] asking to meet him next year so he can elaborate further on this.
- 02-11-2016 - [Personal name 46] replied saying “not a problem” and to call him in December as it’s a quieter month.
- 23-03-2017 - I emailed [Personal name 46] asking if he has time to meet in the following months - he replied on May he has time; would need to ask permission from his manager - I said I would remind him on 18th April.
- 18-04-2017 - I emailed [Personal name 46], he replied he will correspond with his director and get back to me on Thursday.
- 10-05-2017 - [Personal name 46] wrote - our meeting will be on 26 May at MSC facilities.
- 26-05-2017 - I went to the site, [Personal name 46] gave me a list of their suppliers so that I can contact them and find out the waste streams destinations -> see report ‘Visit at [Company name 27]’.
- 27-05-2017 - I emailed [Personal name 46] asking a few questions in relation to our previous meeting.
- 30-05-2017 - I emailed [Personal name 46] asking some quick questions and said I would get back with the updated spreadsheet.
- 31-05-2017 - I sent an email to the recycling facilities referred to by [Company name 27]; [Company name 26], [Company name 21], [Company name 9], [Company name 14], [Company name 5], [Company name 43], [Company name 50], [Company name 35]
- 31-05-2017 - [Company name 9] ([Personal name 1]) replied saying they don’t deal with UCL fit-out waste but just the everyday waste - They mentioned the following
Appendices

suppliers: [Company name 32], [Company name 31], [Company name 7], [Company name 16], [Company name 37].

- 01-05-2017 -[Company name 14] ([Personal name 7]) replied providing three pamphlets, none of them useful.
- 01-06-2017 -[Company name 26] replied sending three pamphlets, two of them provide a brief explanation on how they recycle, but not the percentages I’m looking for.
- 08-06-2017 -[Company name 5] ([Company name 48]) ([Personal name 48]) replied a text explaining the recycling process, mentioning the final destinations, and providing percentages for these -I wrote back asking where they sent the aggregate to become building blocks.
- 09-06-2017 -Lee from [Company name 5] wrote back responding my question.
- 12-06-2017 -I wrote to [Company name 26] asking three questions: the waste streams' shares, about some particular component streams, and locations of the recycling facilities.
- 12-06-2017 -I wrote to [Company name 9] asking again for plasterboard and timber destinations.
- 14-06-2017 -[Personal name 46] shared [Company name 27]'s waste stream shares via email.
- 19-06-2017 -I wrote to [Company name 35] asking for the waste streams shares and about building components such as carpet.
- 19-06-2017 -[Personal name 59] ([Company name 26]) shared the Recycling Rate report for May 2017, it's not very useful -I replied asking where they send their waste streams.
- 21-06-2017 -[Personal name 59] ([Company name 26]) replied saying all waste streams are kept within the UK except for RDF which is sent to Holland or Germany.

26 May 2017
Code: WC2_01
Subject: Site visit to [Company name 27], meeting with [Personal name 46]

This visit was conducted after I received his filled-in questionnaire (on 19-10-2016), which I sent via email.

Introduction (to give when I meet him)

This PhD project focuses on the material flow in building fit-out projects. It is carried out by myself and supervised by Ben Croxford at UCL. One of the main aims of the project is to trace the paths of different waste streams throughout the involved supply chain.

It is worth mentioning that UCL Ethics and Data Protection policies require to preserve full confidentiality of all information. On the other hand, any work generated on [Company name 27] during this PhD and the final thesis can of course be shared with the company.

1. Questions related to Q&A

0) Generic comments.
Appendices

*[Company name 27] seems small - we chatted for two hours in a room upstairs in the “shed”
-[Personal name 46] seems cool, has a big tattoo on his left arm, 4 children: 3, 6, 9 and 12 years old, lives 10 minutes away, apparently his father started the business

* he gave me: Suppliers list (see below), waste report example, and stickers

- Wood -> goes abroad mainly
- Plasterboard -> is taken to [Company name 9] -> then to British Gypsum
- Hazardous waste goes on drums
- Some furniture deteriorates in the driving -> cannot sell it
- Mixed waste is not a waste stream
- Everything can be mixed waste except for hazardous and plasterboard, because of regulations
- They segregate onsite: metal, wood, plasterboard, and hardcore
- Client gets charge £250 after three strikes of sending contaminated plasterboard
- Mixed waste is segregated if it gets to their MRF, however if they collect it in London it’s delivered as mixed waste in London right away, even though they’d have to pay more to hand-in mixed waste (would not be cost-effective to transport it to their MRF)
- They only use bins, not Skips are these get overfilled
- 7 years ago there were just 7 companies like this, nowadays there are 25 of them

[Company name 27] suppliers list:
1) In the Q&A you mentioned some measures that can help increase the rate of reuse and closed-loop recycling: measures such as 1) pre-refurbishment audit, 2) material segregation on site, and 3) set-up take-back schemes. Can you think of any other measure? How do you carry out the process for take-back schemes?

- make sure items don’t get damaged in transportation
- take back schemes should be carried out before items arrive MRF

2) If client delivers mixed waste, do you give them back a report with the material breakdown of this mixed waste?

- No, if they give mixed waste is treated as mixed waste for the client
- It’s only cost-effective for the client segregating onsite above certain total waste weight (over 100t [Personal name 46] said as example)

3) It’s quite an interesting point the fact that there is not set standard for waste firms, and there is no way of knowing whether they are doing what they’re saying. How do you think such a regulatory standard could be like?

- accreditations such as LEED are encouraging to follow a standard

| Company name 5 | postcode, company phone number, company email | Glass mixed, Glass pane |
| Company name 9 | postcode, company phone number, company email | Plasterboard, Wood |
| Company name 14 ( Wandsworth) | postcode, company phone number, company email | Ferrous metal, Non-ferrous metal |
| Company name 21 | postcode, company phone number, company email | Hardcore, Mixed waste, Paper/Cardboard |
| Company name 26 | postcode*, company phone number, company email | Hardcore/Soil, Mixed waste, Paper/Cardboard, Plasterboard, Plastic, Wood |
| Company name 35 | postcode, company phone number, company email | Hardcore, Mixed waste, Paper/Cardboard, Plasterboard, Wood |
| Company name 43 | postcode, company phone number, company email | Appliances, Batteries, Fire extinguisher, Flourescent tubes, WEEE |
| Company name 50 | postcode, company phone number, company email | Adhesives, Paint |
- The Environmental Agency oversees this

4) You mentioned the following waste streams that [Company name 27] commonly deals with: 1) plasterboard, 2) metal, 3) wood, 4) plastic, 5) insulation, 6) cardboard/paper, 7) polystyrene. Which of these waste streams are more difficult to manage and recycle? On the contrary, which are easier to manage and recycle?

**More of a mess:**
- Plastic -> there are many types and grades
- Insulation -> they have no experience/expertise to sort this waste stream -> goes out as mixed waste  - It’s a light weight material and “does not hit the scale”
- Ceramics
- Soils

**Less of a mess:**
- Metal
- Glass
- Plasterboard
- Hardcore (concrete, bricks, gravel, marble, screed, not ceramic, not soil) -> they don’t get charge for handing-in aggregates

5) Which do you consider are the most highly reusable building components (e.g. sockets)? Do you have much influence on the reuse of building components?
- raised access flooring
- office furniture
- ceiling tiles (sometimes damaged in transport)
* cable never gets reused, as it has high material value (£2k a ton)

6) What do you store on your facilities to be reused?
* they recently started storing items to be reused
- fire extinguishers
- PPE
- toolbox
- carpet
- lockers
- construction yellow lights
- ceiling
- furniture
Appendices 268

- pallets

_How do you sell these items?_

- Many of them get reused in subsequent fit-out products, normally with the same client that delivered them, sometimes with different client
- Furniture goes to Reclamation Yards or London Used Furniture Stores

2. Questions regarding building components and waste streams

**BUILDING COMPONENTS:** Are _these usually broken into different waste streams or are they treated as inseparable components?_

- **Electrical socket:** [plastic & metal] OR just WEEE -> both, they strip the plastic and metal, while the batteries and boards go out as WEEE
- **Electrical cable:** [metal] OR just WEEE -> metal
- **Fire alarm:** [plastic & metal] OR just WEEE -> either stripped (same as socket) or reused (70-80%), previously checked by expert, normally by the original client
- **Appliances (Fridge/Oven)** [metal] OR just WEEE -> treated first as hazardous > send to supplier > supplier de-gas it and then it’s treated as metal
- **Fluorescent tubes:** [glass & metal & mercury] -> treated as Fluorescent tubes (hazardous) > put in a coffin and sent to [Company name 43]
- **Carpet:** [textile & plastic] OR just carpet -> regular carpet is treated as mixed waste - carpet tiles are sent as mixed waste to [Company name 26]s (50%) or reused (50%)
- **Suspended ceiling tiles:** [mineral fibre] OR ceiling tiles -> offcuts and the ones with holes go to supplier (50%) as ceiling tiles as it’s note possible for [Company name 27] to separate them, or are reused (50%)
- **Raised access floor:** [timber / metal] OR access floor -> it goes as timber and/or metal or gets reused
- **Hazardous elements:**
  - Fire extinguisher -> if it’s outdates goes as hazardous, otherwise reused
  - Fridge/Freezer -> see Appliances above
  - Refrigerant gasses -> don’t get much of this
  - Waste oils -> they get minimal of this, it goes in drums as hazardous

**WASTE STREAMS:** Are _these included within a waste category (e.g. glass/hardcore) or correspond to a different waste stream?_

- **Ceramic** (sink/toilet/wall pane/floor tiles) -> ceramics
- **Fibreglass** (ductwork/ceiling tiles) -> mixed waste, don’t get too much
- **Marble** (hard flooring) -> hardcore
- **Glass mineral wool** (insulation/ceiling tiles) -> insulation
• **Rock mineral wool** (insulation) -> insulation
• **Stone** (hard wall covering) -> hardcore
• **Cellulose** (insulation/some ceiling tiles) [Paper?] -> don’t get much
• **MDF, Woodchip** [Wood?] -> goes out as “dirty wood” (containing man-made substances) > some suppliers charge the same as mixed waste to collect it
• **Phenolic foam, Polystyrene, Polyurethane** (insulation) [Insulation?] -> insulation
• **PVC** (ductwork/window frame) [Plastics?] -> hard plastics > hard plastics are good, they get £30 a ton

3. Characterisation of waste stream destinations

Mentioned before: 1) **plasterboard**, 2) **metal**, 3) **wood**, 4) **plastic**, 5) **insulation**, 6) **cardboard/paper**, 7) **polystyrene** -> Use chart

Next steps:
- [Personal name 46] told me he can create a waste report for [Company name 27], i.e., average percentages of the waste streams they collect/receive -> remind him
- [Personal name 46] said I can contact their suppliers in order to fill the chart

27 May 2017
Code: WC2_02
Subject: I emailed asking a few questions in relation to our previous meeting

[Personal name 46] replied the following:

1) Which supplier deals with 'Insulation'? I'm guessing the same ones that deal with 'Mixed waste' ([Company name 21], [Company name 26] and [Company name 35])?
   a. Yes.

2) Do "unreclaimed" ceiling tiles go out as 'Mixed waste'?
   a. Yes they go out for processing as Mixed waste at current.

3) What is the estimated percentage of office furniture that gets reclaimed at [Company name 27]?
   a. In proportion of our total waste no more than 5% at current, however this is increasing, please note this does not account for direct reuse of material (from site to buyer), this is only based on material in [Company name 27] yard that is sent out for reuse.

4) Is it correct that the following components get stripped at [Company name 27] facilities (when not reclaimed): sockets, fire alarm, raised access flooring?
   a. We strip non-hazardous waste items down into their component streams at [Company name 27] yard, we have attempted to strip Raised access flooring however this requires heavy machinery so we send RAF out to be stripped down to Connects Waste.
**14 June 2017**  
**Code: WC2_03**  
**Subject:** [Personal name 46] shared [Company name 27]’s waste stream shares via email  
Reported period: 01-01-2017 to 31-03-2017  
Recycling rate: 99.4%  
Recovered for energy: 0.6%  

**The following figures are given in tonnes:**  
- Hardcore/soil: 11.900  
- Wood: 25.060  
- Glass: 13.020  
- Plastic: 0.000  
- Metal mix: 32.840  
- Plasterboard: 72.587  
- Mixed waste: 66.254  
- Paper/Card: 6.180  
- Carpet tiles: 0.000  
- Hazardous: 0.620  

TOTAL COLLECTED: 228.461 tonnes

**19 June 2017**  
**Code: WC2_04**  
**Subject:** Email conversation with [Personal name 59] from [Company name 26]  

**My notes:**  
After I sent an email asking for their waste streams shares on 12-06-2017, [Personal name 59] Edmonson replied the following and shared their recycling figures for May 2017. None of it is particularly useful for my question. However, the pdf she sent might be helpful to better understand some of the recycling processes of particular waste streams.

Hi Miguel,

Where possible we use recycling partners within the UK this enables us to keep the logistics at a sensible level. The residue from waste is sent to the continent usually Holland and Germany due to the fact that the UK has no outlets for this at the moment. (please refer to RDF page on our Material Data Sheets)

Our overall recycling rate for May is 97.2% which covers the materials you have enquired about. The other 2.8% is (RDF) waste to energy which goes to the continent.
For further information on the waste industry we update our twitter page weekly with interesting information.

Good luck with your studies.

Kind regards,

[Personal name 59]

Service Supplier Co-ordinator

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Good morning,

Thank you for your response and for your support.

May I please lastly ask you about the following waste streams: 'paper/cardboard', 'plastic', 'metals' and 'wood':

- What would be the estimate average of these waste streams that is respectively sent abroad? Where is it sent to?

This is to understand the tendency of waste streams paths.

Many thanks for your kind support.

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Hi Miguel,

Please find reattached.

Yes all goes onto Fuel for Energy. Please refer to RDF section in our Material Data Sheets as previously sent.


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Good morning [Personal name 59],

Thank you for your response. Unfortunately the attachment is missing?

May I please ask you if the waste lost due to contamination can be all used as fuel for energy? or what happens with the proportion that can’t be used as fuel?

Many thanks for your kind support!
Good Afternoon Miguel,

Further to your email dated 12th June 2017.

I have reattached our [Company name 26] Group’s Recycling Figures for May 2017.

The waste streams listed on the left hand side of our Monthly Recycling Figures are all the waste streams that our company handles. The Average Recycled Percentages against each waste stream is the percentage we have achieved across both our processing centres. This is calculated on all processed loads despatched from our sites over our weighbridges. We calculate all the different waste streams by a variety of individual weight loaders and machinery running belts.

The overall recycling percentage is calculated upon all processed materials and its individual category once the full procedure is completed. We transport different materials between our depots depending on the specialist recycling equipment required. Therefore, any material declassified throughout our plant would be re-diverted to another category and recorded/weighed by our weighbridge accordingly.

Tonnage: These weight amounts are collected from our weighbridges, machinery/belts and our overall company’s tonnages for incoming and outgoing. However, processing times and total stock levels within both our facilities can also affect our reporting due to our extensive recycling procedures, storage availability and conditions within our depots, our recycling partner’s facilities along with market trends can result in a turnaround varying.

For example 80% of coloured paper and magazines received were recycled, 20% was lost due to contamination.

For example 98% of Timber received was recycled, 2% was lost due to contamination.

To summarise for May 2017:

97.2% was our Groups overall Recycling Rate for May 2017.

2.8% was sent as Fuel for Energy.

With regards to your question “What are the estimated percentages of each waste stream that arrives to your company?” I can confirm that approximately 80% of waste received into our Material Recycling Facilities is Mixed Construction and Demolition Waste (EWC Code 17 09 04), 10% is Mixed Municipal Waste (20 03 01), 5% Plasterboard (EWC Code 17 08 02), 1% Glass (EWC Code 17 02 02), 2% Greenwaste/Soil (EWC Code 02 01 03) 1% Batteries (EWC Code 16 06 02) and WEEE Electrical Goods (20 01 35), 1% Food (20 01 08).

The waste streams you listed i.e Carpet tiles, Office Furniture, Insulation usually come into our Material Recycling Facilities as Mixed Construction and Demolition Waste but go through our extensive waste processing procedures.

I can confirm that our Recycling partners are located all around the UK and other Continents.

We hope this helps and wish you every success with your studies.
D.3 Fit-out case studies

D.3.1 Bank offices

Summary

- Main contact: [Personal name 35] ([personal email]), [Company name 33], introduces by [Personal name 17]
- Project started around Dec 2015, ongoing
- 04-07-2016 -met him at his office
- 27-09-2016 -Visited the site, took notes and pictures.
- [Personal name 35] then send me some files (take-back schemes, and SWMP’s), and gave me two waste contractors contacts.
- 23-10-2016 -wrote him asking about design team and specification of supplies.
- 24-10-2016 -replied answering each of the three questions, told me to contact him for anything else

04 July 2016
Code: CS0_01
Subject: Meeting with [Personal name 35], [Company name 33]

- He is the Sustainability Manager, really nice young guy. He seems to be the most helpful towards my project so far.
- His boss is actually in the SKA technical committee.
- They outsource [Company name 29] and [Company name 27] for waste management.
- The UK average fit-out recycling is 95%, LEED asks less than this, 75%
- They prefer SKA rather than BREEAM because is simpler and more straightforward
- Plasterboard gets recycled very efficiently, mainly by British Gypsum
- [Personal name 35] says he’ll surely find some fit-out projects for me. If he doesn’t mail me, I shall write him next week.

26 September 2016
Code: CS0_02
Subject: Preparing for Site visit 1, Bank offices

Location: 10 Upper Bank Street, Canary Wharf
Guide: [Personal name 35], Environmental and Sustainability Manager
Contact details: [personal email], [personal phone number]

*see photos in the corresponding folder

Questions to ask, related to his last email:

Why you say LEED is very easy when it comes to waste?

You said “less emphasis on reuse and sending materials back to manufacture”, then what are the means of landfill diversion in LEED?
What are the goals in LEED? *will check these last questions myself

**Thesis questions I should ask him:**

What percentage of the removed components and material gets recycled and reused in fit-outs (in the London case studies)?

What happens with the different waste streams after they are removed throughout the supply chain?

How can the loop be closed in fit-outs between start-point in the waste stream (where waste is generated) and endpoint (where the waste gets reprocessed into new materials)?

What incentivises the decision makers to choose to recycle/reuse the removed components and materials?

Which actors in the supply chain are more influential when deciding to have a circular fit-out?

**Other questions:**

How do you do the inventory for outgoing and ingoing components and material? Do you use some kind of software or spreadsheet?

**27 September 2016**

**Code: CS0_03**

**Subject: Site visit 1, Bank offices**

Today I met with [Personal name 35] and [Personal name 88] from the same company. [Personal name 35] was very nice and helpful, answering my questions (seemed a bit desperate at the end), [Personal name 88] was a little shy but paying attention to my questions. In practice, they were not able to answer many of the questions I prepared, other questions seemed un-practical to ask at the moment, due to time constraints. Below are my notes from the site visit.

The fitout is for [Company name 12]

twelve floors of the building

It will take approximately two years

[Personal name 35] mentioned the fit-out was already in Cat A (flooring) when they got there, so they’re doing the Cat B (furniture)

[Company name 33] average recycling rate is 94%, while this FO will be 97%, which [Personal name 35] says it’s more downcycling

They’re reusing less than 5% (this is my estimate) which presumably is ductwork and raised flooring

Metallic raised access flooring was already in, they are reusing it, maybe it’s been there more than ten years, I could see that this floor is mounted over some posts

They are installing carpet, linen, and stone tiling

Ceiling tiles were going to be reused but it was not cost beneficial
Appendices

Strip-out contractors: LDD

Waste contractors: [Company name 29]

[Company name 29] takes waste, separates it and sometimes shreds it, then waste is taken to someone else to be recycled or incinerated.

Hazardous waste is not taken such as: asbestos, oil-based paints, aerosols, mastiks, and batteries.

[Company name 29] charges less if waste is separated.

[Company name 33] (OB) tries to separate waste in order to be charged less by [Company name 29]

Metal waste cost less to be taken away, then plastics…. Assorted waste can be more expensive that landfilling.

They had some cut-offs from plasterboard partitions (picture).

[Personal name 35] said although British Gypsum and Knauf have take-back scheme is still expensive.

Armstrong take-back is free, but only for fibreboard ceiling after 2000.

Knauf does plasterboard and insulation, however insulation does not have take-back schemes as if it is difficult to recycle.

Cause insulation degrades and it is difficult to strip-out.

Had some waste from stripped-out toilet flooring (picture), which is hard to rip-out without breaking.

It's usually used for aggregates and [Personal name 35] said sometimes it's incinerated.

Packaging: normally goes to [Company name 29] bins, where gets recycled, sometimes gets sent back to manufacturer to reuse, sometimes the use blankets for furniture.

Cable wheels can be reused up to seven times.

Pallets can be reused too, but only the good ones (hard wood), [Personal name 35] said suppliers should use the good ones.

[Personal name 35] said, reuse in bigger fit-outs is more feasible because of more time and more space, while in smaller FO’s reuse is incentivised by costs reduction (as small FO have low budget).

I asked what they use to inventory the waste, [Personal name 35] said they use an Internal Site Waste Management Plan.

The client ([Company name 12]) has its own Project Manager (Mace), QS and Arch.

OB are the contractors which in turn have their own PM, QS, etc.

Remind him to send me:
Take-back schemes of the products they use

[Company name 29] contact

Waste contractors fees

Internal Site Waste Management Plan

Sent this email asking further questions -replied on 23 October 2016

Hi [Personal name 35],

Could I please ask you some questions about the [Company name 12] fit-out? I apologise for not having asked them when we were on-site. More questions arise as I try to analyse the process:

- Who specified the building products to use (such as, floor/wall coverings, lighting fixtures, ductwork, etc.)? Are these specified by [Company name 33] or by the design team? The architects on this project were T P Bennett, so they would have specified the majority of the finishes and products. Though this was a design and build contract, so we did have designers on the project, but the majority was done by the architects.

- Who was the design team for this fit-out? Do you know if they have a sustainability person or if they outsourced one (like a carbon profiling consultant)? The design team were T P Bennett; I am not too sure in regards to that though. Worth a google.

- You mentioned the strip-out was conducted by LDD... Was this contractor assigned by the design team? Who decides what to do with the strip-out waste? LDD or the design team? LDD was employed by [Company name 33], on 95% of projects we will employ the strip out contractor – it is very rare the strip out is done before we come on board. The strip out waste is usually down to the strip out contractor to manage – we do not have much input on this unless it is a BREEAM/SKA project.

D.3.2 UKGBC offices

Summary
- Main contact: [Personal name 55] ([personal email]), [Company name 42]
- Started: 8 August 2016; Finished: October 2016
- Went to [Personal name 55]’s office twice (04-08-2016 and 14-10-2016). She gave me a chart with the specified building components, a plan, and then sent me some EPD’s and SWMP. On the second meeting I asked her a Q&A and she explained me the supply chain diagram for the project.
- 17-10-2016 -[Personal name 55] sent email to [Personal name 11], asking about waste contractor contact ([Company name 29]), [Personal name 11] replied saying that her colleague ([Personal name 35]) had already put me in contact with [Personal name 3] from [Company name 29].
- 08-06-2017 -[Personal name 55] replied sending me an updated Fitout Matrix with these quantities.
04 August 2016  
Code: CS1_01  
Subject: Meeting with [Personal name 55] from [Company name 42], about fit-out at the Building Centre

- Architect/Designer: [Company name 4]  
- Project Manager/Quantity surveyors: [Company name 44]  
- Contractor: [Company name 33]

- This fit-out will be at one of the offices of UKGBC in the Building Centre. [Company name 42] will do the carbon profiling.

- [Personal name 55] is partly in charge of this, and will help me. She did a Masters at EDE and she’s friends with Mad[Personal name 22].

- The office space is 150 m2, the fit-out will be low-cost.

- Aims: well-being, lowest embodied carbon fit-out in the UK, 95% landfill diversion by reuse, repurpose, recycle, and charities.

- Using BREEAM as KPI's but not certifying because of the low cost profile.

- Apparently last fit-out was 15 years ago. [Personal name 55] says in general fit-outs take place according to leases: 5, 10 or 15 years.

- Using BS EN 15978: Sustainability of construction works. Assessment of environmental performance of buildings. Calculation method. *** I wonder for what exactly

- Also using their own tool, WLCA (excel spreadsheet), certified by BRIA and considered in BREEAM.

- EPD’s help a lot for this calculations because they include: carbon figures, lifespan, ingredients, recyclability or end-of-life purpose of components.

- Also helpful for obtaining components data is Ace Database, developed from a guy from Bath. Outdated, ten years old though.

- [Company name 42] compare fit-outs from other of their projects. Also they compare them to the case where no low-carbon measures are taken.

- [Company name 42] has recently done fit-outs for WWF (280 KgC02/m2) and Google (355). The latter used Wisa plywood which [Personal name 55] says is really nice. This UKGBC fit-out aims for 43 kgCO2/m2.

- [Personal name 55] says they meet with designers every week.

- Higher costs will be labour and MEP services (Mechanical, Electrical and Plumbing).
They will start on-site on 8\textsuperscript{th} August and aim to finish at the end of September. Occupants were moved to a temporary space.

They were going to use double glazing to make the large meeting room divisible, but couldn’t afford it.

Inventory:

<table>
<thead>
<tr>
<th>Reused</th>
<th>New</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Raised floor</td>
<td>- Interface carpeting (including take-back for currently installed tiles)</td>
</tr>
<tr>
<td>- Lighting fittings (partly because they could not procure new ones on time)</td>
<td>- Linoleum flooring for kitchen</td>
</tr>
<tr>
<td>- Chairs and furniture</td>
<td>- Partitions, which will be bolted for later reuse or adaptations. Using the brand Breathaboard</td>
</tr>
<tr>
<td>- Some glass partitions, some reused, one repurposed as hot desks</td>
<td>- Desks and chairs; second-hand from Rype. Furniture has low VOC after two years of use</td>
</tr>
<tr>
<td>- One door, other door as hot desk</td>
<td>- Paint, low-carbon and low-VOC</td>
</tr>
<tr>
<td>- Cupboards</td>
<td>- Timber stats</td>
</tr>
</tbody>
</table>

14 October 2016

Code: CS1_02

Subject: Meeting 2 with [Personal name 55], [Company name 42], about fit-out project in Building Centre (UKGBC)

Was there a strip-out?

Yes, the following was removed:

- Partitions (metal stud [framing] + plasterboard cladding) -recycle [Company name 29]
- Lighting fittings -reused off-site
- Ductwork -recycle [Company name 29]
- Carpet - take-back (Forbo)
- *There was no ceiling

The “waste” (or removed components) was generated at strip-out stage or at the fit-out?

- Maybe some cut-offs, taken by [Company name 29]

How were components reused?

- Lighting fittings: reused offsite in Building Centre
- Raised access floor: reused onsite (+5% new)
- Furniture: reused onsite (80%)
- 3 doors (re-positioned)
- 3 glazed partitions (re-positioned)
- 2 glazed partitions (re-purposed as whiteboards)
- *installed a reused glazed partitions frame from other project (Fusion supplier did it)
Which new components were installed?
- Light fittings: Phillips LED, in a scheme were these are installed for free, yield reduced electricity bill, the savings in this bill are paid to Phillips until covering the price (applicable for projects no higher than £50k to help small companies)
- Furniture (20%): second-hand from Rype -2 tables, 4 steel-case chairs

% of recycling: 98
% of reuse: >50 (I’d say)
% landfilling: 2

What could not be recycled?
- Maybe some plaster from plasterboards

Do you know what stuff got recycled into?
- No

Actors involved in the supply chain? e.g. Design team (PM, QS, Arc, PEM), Strip-out contractor?, Waste contractor, Recycling facilities, Fit-out contractor.

Design team:
- Project Manager: unknown -> coordinate whole project, organise design team meetings (agenda), assign responsibilities and timings, take notes and circulate them
- Arch: [Company name 4] (also take decision on materials)
- MnE: [Company name 56]
- QS: [Company name 44]
- Carbon Profiling: [Company name 42]

Strip-out and Fit-out Contractor:
- [Company name 33]: with its own PM, MnE, QS, Sust.

Waste contractor
- [Company name 29]

Recycling facilities
- unknown

What did [Company name 42] do in this project?
- They’re in charge of sustainability
- They carry out whole-life assessment (from design, construction, to completion)
- They do consulting on sustainable, low-carbon materials
- Would use BREEAM if they were to use a cert. scheme

Can I get the contact to waste contractors, and recycling facilities?
Yes, send [Personal name 55] email to remind her; mentioned Camila (ML sust manager)


**D.3.3 UCL Confucius Institute**

**Summary**

- Main contacts: [Personal name 24] ([personal email]), UCL -[Company name 18] Architects ([personal email]; [personal email])
- Started: 12-Dec-2016    Finished: 05-Jun-2017
- Design process started around February 2016, project got paused because under-budgeted
- 12-01-2016 -went to an introductory meeting about the project in [Company name 18]’s office
- 20-04-2016 -I wrote to [Personal name 47] asking for specification matrix.
- 21-04-2016 -[Personal name 47] sent the design specifications (they called it NBS).
- 23-11-2016 -Attended SKA office scoping meeting at [Company name 33]’s Office with [Personal name 24], [Personal name 38], [Personal name 11], [Personal name 78], and QS -[Personal name 38] told me to send [Personal name 35] an email to follow up the case study
- 24-11-2016 -I sent email to [Personal name 35] and [Personal name 78] letting them know what I’ll be looking and what I need access to
- 25-11-2016 -[Personal name 78] replied saying they’ll be taking possession of the site on 5th Dec and that I could have a site visit on the 8th. I replied thanking him and then he sent me draft SWMP
- 08-12-2016 -site visit 1. [Personal name 78] was very nice to show me around and explain some stuff. I took some notes and pictures. I’m supposed to go back when I return from Mexico.
- 09-12-2016 -site visit 2 -did an inventory. Annotated all elements using some plans I made and also took pictures.
- 03-02-2017 -site visit 3 -after Mexico, [Personal name 78] took me around, everything was stripped out
- 07-02-2017 -site visit 4 -with [Personal name 24], [Personal name 66] and [Personal name 62], both seem nice persons and were smiley towards me

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*Explain the order of this in a diagram form:*

![Diagram of project team and contractors]
27-03-2017 -site visit 5 -went without notice, [Personal name 78] was there, I looked around by myself -Will write an email to [Personal name 78] asking if it’s possible to know amount of waste streams (from mixed waste tickets)

28-03-2017 -replied saying that [Company name 29] will give detail info at the end of the project.

11-04-2017 -site visit 6 -talked with [Personal name 78] at IoE -he’ll put me in contact with [Company name 29] and will send me the OMM in a month.

05-05-2017 -site visit 7 -counted some remaining components and measured all doors

20-06-2017 -I wrote to [Personal name 78] -He said the works are done and project has been handed to [Personal name 81] (UCL Estates) -I wrote back asking for the OMM and SWMP -I sent an email to Valerie

27-06-2017 -site visit 8 -[Personal name 81] showed me around the site after fit-out

04-07-2017 -Mary sent final SWMP and OMM.

15-12-2017 -I emailed [Personal name 78] asking a few questions about the waste collection process -he replied right away.

12 January 2016

Code: CS2_01

Subject: Meeting about a fit-out at UCL

Confucius Institute of Schools

[Personal name 66] (architect), [Personal name 24] (project management from UCL), [Personal name 56] (also architect I suppose)

Lower ground floor –It’s been used as a residential building

Upper ground floor –office rooms

First floor – office rooms –want to maximise space

They promote Chinese language and culture –there are language courses –and also they design courses

Some of the space will be lecture rooms, sometimes they do exhibitions, it works as a cultural embassy sometimes

The envelope –just cleaning the façade, replace some of the windows (south), heritage would not let do more, not even double glazing, they’re adding some insulation to the roof

Lower ground –changing plan for bathroom and kitchen, opening a wall between lecture rooms

Upper ground floor- adding a deck to the back garden

First floor –leaving the partitions, but adding some doors to connect

Second floor –remove the bathroom to have a big staircase to the office

Third floor –desks for eight people plus hot desks

Raising and changing the ceiling
LIGHTING: Three types of light fitting, mostly LED

FLOORS: Aiming to keep most flooring, except bathrooms (tiles), cantine (timber), lecture rooms (rubber floor)

WALLS: Replaster all the existing walls

FURNITURE: Getting all new from Chinese Design Centre (are they certified?) and some British

ENERGY: It will have boiler and radiators, but should be prepared to connect to the future central heating

WASTE: Furniture is old,

88,000 pounds is the budget

Construction phase – July to Jan

Make a list of the aims

End of February -scope

23 November 2016
Code: CS2_02
Subject: SKA scoping for UCL Confucius project

At [Company name 18] Office –[company address]

- UCL Project Manager: [Personal name 66]
- Architect: [Company name 18]
- Fit-out Contractor: [Company name 33]
- Waste contractor: [Company name 29]

Meeting Attendees:

- [Personal name 24] (UCL Sustainability Officer)
- [Personal name 38] ([Company name 33] Head of Environmental and Sustainability -looks like my friend Uriostegui)
- Camila Read ([Company name 33] Environmental and Sustainability Manager - young, blue eyes, have I seen him/her somewhere else?) *same as [Personal name 35] [personal email]
- [Personal name 84] ([Company name 33] Information Manager -blonde 60yr old woman)
- [Personal name 78] ([Company name 33] Site Manager -soldier looking, Italian, short Mohican haircut) [personal email]
- [Personal name 83] ([Company name 57] QS -white guy, black hair, seems nice)

I introduced myself, then [Personal name 24] explained that I would be following the waste. They understood and suggested that I can get in contact with the waste contractor and further down the supply chain
[Personal name 78] said he could show me the site before and after I’m gone

Strip-out will take place in the first three weeks of January

He might have mentioned he’d be doing a SWMP

SKA scope:

- NT) Building it’s empty – no desks or chairs
- NT) Thermal comfort modelling not in scope -it costs £1K
- ?) Glare -there will be black-out blinds
- NT) Thermal sub-metering
- NT) Refrigerant detection
- NT) Low VOC’s finishes – Camila Read mentioned varnishes and suspended ceilings
- T) SWMP
- NT) Kitchen fittings -difficult to achieve

Going in:

- T) Timber, partitions, ceiling
- T) Hardflooring -rubberised floor
- T) Softflooring -carpet tiles
- T) Furniture -maybe Chinese
- T) Wall coverings -FSC wall paper
- T) Doors -reusing on-site

Going out:

- T) Floor finishes sent to landfill -Timber flooring -can’t reuse because some of it got damaged

SKA measures

- 80 measures in Scope *65 targeted
- For gold rating:
  - 60 Required (80x0.75)
  - 20 Gateway Threshold (80x0.25)
  - 15 Gateway Must (20x0.75 OR 60x0.25)

They mentioned that [Personal name 24] should be the SKA assessor, [Personal name 24] said no, QS said they have budget for that. -[Personal name 24] later told me he got upset that they’re trying to impose on him being that he’s representing the client

To do:

[Personal name 38] talked to me at the end saying that I should send [Personal name 35] an email saying:

- What I’m looking for, or what I’ll be looking at
- What I need access to
- Dates I’m available

Will be something like this:
Hi [Personal name 35],

I hope this email finds you well.

Yesterday (Wed 23rd) I was in the SKA scoping meeting for the UCL Confucius project, for which [Company name 33] is the main contractor.

[Personal name 38] asked me to send you an email letting you know what I'll be looking at in this fit-out project and what I would need access to.

I will be looking at:

- Specification of materials and components going in or reused on-site
- The waste streams going out, and the paths they follow

I would like access to:

- Fit-out Specification Matrix (I'm not sure this is how you call it)
- Fit-out SWMP
- Permission to look at the Recycle Report from Waste Contractor

Dates:

- I'll be on annual leave from 15th Dec to 15th Jan. Apart from this month I am readily available anytime.

[Personal name 78] (copied in) kindly offered to show me around the site before and after my leave. I would really appreciate that. Please let me know if this will be possible.

08 December 2016
Code: CS2_03
Subject: Site visit 1 -before fit-out

With [Personal name 78] ([personal phone number], [personal email]) - I arrived at 12:00 on site (next to Farmers Market) -[Personal name 78] was nice and was patient to explain various things –

The building is 3 floors + lower ground - about 5 rooms per floor, and rooms on lower ground - it will all be fitted-out

[Personal name 78] told me there are three types or stages of strip out:

1. Hazardous materials (such as asbestos) - this will happen on 13th Dec
   - Asbestos were commonly used for its fire-resistance, but they were banned in 2000 - as they can cause cancer or asbestosis
   - On this site there are asbestos in the 1st floor doors (the cladding panels shown in the picture)
   - > these asbestos panels will be weighted and sent to a Special Centre either in Essex, Sussex or Kent – [Personal name 66] said they will get buried

2. Softstrip - this includes anything but structural
   - [Personal name 78] took me to the 3rd floor kitchen, in this rooms the Softstrip will include: blinds, blinds rail, cupboards, counter, sink, floor vinyl + plywood + boards
(actual wood, but nowadays made of MDF), electrical cabling, doors, and boiler (all shown in the pictures)

- [Company name 11] (strip-out contractor) will do the job - they have their own waste license but will be taking the waste to [Company name 29]
- * Sink and kitchen elements are in a fair state, but they won’t be reused - [Personal name 78] said there is no market for them

3. Building works - anything structural implying materials as concrete, hardcore, timber

- > Building works contractor (not assigned yet) will tear down some walls (at least he mentioned two) - then waste will be taken to [Company name 29] as well

4. General waste - includes offcuts, boxes, packaging, spare material, anything generated during the process that is not inherently part of the building

- > Will also go to [Company name 29]

Random notes:

- The whole block (where building is) was finished on 1847
- [Personal name 78] does a preliminary SWMP and a final SWMP (taking into account sub-contractors’ reports) and compare the both
- While I was there [Company name 29] came to deliver some 330lt bins - they won’t sort waste on this site because it’s a small project and materials are not enough to make sorting worth it
- Electrical installation seemed pretty messy, they agreed and told me they’d redo it - [Personal name 78] showed me an armoured cable

List of elements I’ve found (Condition: Poor, Fair, Good, Excellent):

<table>
<thead>
<tr>
<th>Stripped-out (all taken to [Company name 29] at barking)</th>
<th>Reused</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carpet - in all rooms and halls - P</td>
<td>Doors ~ 9 - probably on other floors but surely 3rd - G - will be reused cause they are heritage, the other ones are newer so they’ll be stripped-out</td>
</tr>
<tr>
<td>Doors x 5 (at least) - on 3rd floor - F</td>
<td>Floorboards (solid timber) - in every room - G</td>
</tr>
<tr>
<td>Doors ~ 5 on other floors - G - SO cause new ones were specified</td>
<td>Windows’ frames and panes - G</td>
</tr>
<tr>
<td>Doors’ asbestos panels on 1st floor - F</td>
<td>Floor plywood - everywhere - F</td>
</tr>
<tr>
<td>Electrical cabling and equipment (plugs) - F and - G</td>
<td>Kitchen cupboards and counter - G</td>
</tr>
<tr>
<td>Floor plywood - everywhere - F</td>
<td>Lighting fittings - E</td>
</tr>
<tr>
<td>Radiators - P</td>
<td>Shelves - almost in every room - E - two of these sets of shelves will go to charity (probably City Farm)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reused</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doors ~ 9 - probably on other floors but surely 3rd - G - will be reused cause they are heritage, the other ones are newer so they’ll be stripped-out</td>
</tr>
<tr>
<td>Floorboards (solid timber) - in every room - G</td>
</tr>
<tr>
<td>Windows’ frames and panes - G</td>
</tr>
<tr>
<td>Shelves - almost in every room - E - two of these sets of shelves will go to charity (probably City Farm)</td>
</tr>
<tr>
<td>Stairs’ nosing (and obviously carpet)</td>
</tr>
<tr>
<td>----------------------------------------</td>
</tr>
<tr>
<td>Wall paper -woodchip type</td>
</tr>
<tr>
<td>Window -small one at the top of the stair-case</td>
</tr>
<tr>
<td>Window’s blinds and rails</td>
</tr>
</tbody>
</table>

Next:

Go again before leaving and count everything. I should go back when I arrive from Mexico.
Maybe get in contact with [Company name 18] for design brief.

09 Dec - Went there next day and did an inventory of everything using plans I drew. Also took some pictures.

Elements that were missing on the previous list:

- Cable duct
- Sinks (kitchen and toilet)
- Counter
- Whiteboards
- Plugs (put them apart)
- Coat rack
- Vinyl flooring
- Toilet
- Tiles (kitchen, above chimney)

Pictures: See corresponding folder

09 December 2016

Code: CS2_04

Subject: Units detailed per floor
<table>
<thead>
<tr>
<th>Item</th>
<th>LG</th>
<th>1st Floor</th>
<th>2nd Floor</th>
<th>3rd Floor</th>
<th>Basement</th>
<th>SUM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blinds</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>15</td>
</tr>
<tr>
<td>Board</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Boiler</td>
<td>1</td>
<td></td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Cableduct [m]</td>
<td>36</td>
<td>36</td>
<td>28</td>
<td>35</td>
<td>15</td>
<td>150.5</td>
</tr>
<tr>
<td>Carpet [m2]</td>
<td>36</td>
<td>43.5</td>
<td>40</td>
<td>43.5</td>
<td>55</td>
<td>218</td>
</tr>
<tr>
<td>Carpet plywood [m2]</td>
<td>36</td>
<td>43.5</td>
<td>40</td>
<td>43.5</td>
<td>55</td>
<td>218</td>
</tr>
<tr>
<td>Counter [m]</td>
<td>3</td>
<td></td>
<td>3.2</td>
<td></td>
<td></td>
<td>6.2</td>
</tr>
<tr>
<td>Cupboards</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>14</td>
</tr>
<tr>
<td>Door</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>14</td>
</tr>
<tr>
<td>Fire alarm</td>
<td>4</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Fire extinguisher</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Flooring - vinyl</td>
<td></td>
<td></td>
<td>1st Kitch</td>
<td>4th Kitch</td>
<td>LG hall, toile</td>
<td>0</td>
</tr>
<tr>
<td>Hanger</td>
<td></td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Light bulb</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Light fitting</td>
<td>6</td>
<td>7</td>
<td>4</td>
<td>4</td>
<td>9</td>
<td>30</td>
</tr>
<tr>
<td>Plugs</td>
<td>12</td>
<td>16</td>
<td>9</td>
<td>20</td>
<td>13</td>
<td>70</td>
</tr>
<tr>
<td>Plugs - ethernet</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11</td>
</tr>
<tr>
<td>Radiator</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>17</td>
</tr>
<tr>
<td>Shelves</td>
<td>13</td>
<td>31</td>
<td>25</td>
<td>15</td>
<td>31</td>
<td>115</td>
</tr>
<tr>
<td>Shelves rails</td>
<td>14</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td>24</td>
</tr>
<tr>
<td>Sink</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Stair handle [m]</td>
<td>4.2</td>
<td>4.2</td>
<td></td>
<td></td>
<td></td>
<td>8.4</td>
</tr>
<tr>
<td>Stairs nosings</td>
<td>24</td>
<td>24</td>
<td>16</td>
<td>16</td>
<td></td>
<td>80</td>
</tr>
<tr>
<td>Toilet</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Toilet paper dispenser</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Toilet sink</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Wall paper</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Wall tiles</td>
<td>158</td>
<td></td>
<td></td>
<td></td>
<td>3.5m2</td>
<td>158</td>
</tr>
<tr>
<td>Window</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

12 December 2016
Code: CS2_05
Subject: Inventory spreadsheet
### 07 February 2017

**Code: CS2_06**

**Subject: Site visit 4 with [Personal name 66] and [Personal name 62]**

- [Personal name 66] and [Personal name 62] both seem nice persons and were smiley towards me
- [Personal name 66] asked [Personal name 78]’s brother about how they were coping with the SKA
- they asked if there was anything Chinese, there was none
- [Personal name 24] pointed out to me that they are recovering some partition walls since it is a listed building, Sam says it takes more time and money to do so
- There is not double glazing in the windows, will they add it?
- They are doing Envirograf on heritage doors to restore them after stripping out the asbestos from them
- They are installing 2 plants in basement, to create electricity and heating

### 27 March 2017

**Code: CS2_07**

<table>
<thead>
<tr>
<th>Item</th>
<th>Units</th>
<th>Quality</th>
<th>Destination</th>
<th>MS (Tony)</th>
<th>Dimensions [cm]</th>
<th>Photo</th>
<th>Item description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blinds</td>
<td>15</td>
<td>P</td>
<td>WC</td>
<td>plastic/textile</td>
<td>*183x116</td>
<td>Y</td>
<td>window pvc blinds</td>
</tr>
<tr>
<td>Board</td>
<td>5</td>
<td>G</td>
<td>WC</td>
<td>timber</td>
<td>*124x70</td>
<td>Y</td>
<td>chalk board</td>
</tr>
<tr>
<td>Boiler</td>
<td>2</td>
<td>E</td>
<td>WC</td>
<td>metal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cable duct [m]</td>
<td>150.5</td>
<td>F</td>
<td>WC</td>
<td>plastic</td>
<td>4x2.5</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Carpet [m2]</td>
<td>218</td>
<td>F</td>
<td>WC</td>
<td>textile</td>
<td>40x40</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Carpet plywood [m2]</td>
<td>218</td>
<td>G</td>
<td>WC</td>
<td>timber</td>
<td>40x40</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Counter [m]</td>
<td>6.2</td>
<td>E</td>
<td>WC</td>
<td>chipboard</td>
<td>60 wide</td>
<td>Y</td>
<td>at kitchens</td>
</tr>
<tr>
<td>Cupboards</td>
<td>14</td>
<td>E</td>
<td>WC</td>
<td>chipboard</td>
<td></td>
<td>Y</td>
<td>at kitchens</td>
</tr>
<tr>
<td>Door</td>
<td>14</td>
<td>F</td>
<td>WC</td>
<td>timber</td>
<td>212x94 &amp; 202x75</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Door frame</td>
<td>14</td>
<td>F</td>
<td></td>
<td>11 reused onsite</td>
<td>timber</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fire alarm</td>
<td>5</td>
<td>P</td>
<td>WC</td>
<td>plastic/copper</td>
<td></td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Fire extinguisher</td>
<td>8</td>
<td>G</td>
<td>reused offsite</td>
<td>metal</td>
<td></td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Floor boards [m2]</td>
<td>218</td>
<td>G</td>
<td>reused onsite</td>
<td>timber</td>
<td></td>
<td>Y</td>
<td>under the carpet</td>
</tr>
<tr>
<td>Floor finishing - vinyl</td>
<td>calculate</td>
<td>P</td>
<td>WC</td>
<td>plastic</td>
<td>Y</td>
<td></td>
<td>N</td>
</tr>
<tr>
<td>Hanger</td>
<td>3</td>
<td>G</td>
<td>WC</td>
<td>timber</td>
<td>60</td>
<td>Y</td>
<td>cloth hanger nailed on door</td>
</tr>
<tr>
<td>Light bulb</td>
<td>4</td>
<td>G</td>
<td>WC</td>
<td>2 glass/gas</td>
<td>100x30 &amp; 131x36</td>
<td>Y</td>
<td>traditional column radiator</td>
</tr>
<tr>
<td>Radiator</td>
<td>17</td>
<td>P</td>
<td>WC</td>
<td>metal</td>
<td>*80x60</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Partition</td>
<td>7</td>
<td>F</td>
<td></td>
<td>plasterboard</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shelves</td>
<td>115</td>
<td>F</td>
<td>XX reused onsite</td>
<td>timber</td>
<td>*150x21</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Shelves rails</td>
<td>24</td>
<td>E</td>
<td>WC</td>
<td>metal</td>
<td></td>
<td>Y</td>
<td>at kitchens</td>
</tr>
<tr>
<td>Sink</td>
<td>2</td>
<td>G</td>
<td>WC</td>
<td>ceramic</td>
<td></td>
<td>Y</td>
<td>at kitchens</td>
</tr>
<tr>
<td>Socket</td>
<td>70</td>
<td>G/E</td>
<td>WC</td>
<td>plastic/metal</td>
<td>14x7</td>
<td>N</td>
<td>two switched outlets</td>
</tr>
<tr>
<td>Socket - ethernet</td>
<td>11</td>
<td>F</td>
<td>WC</td>
<td>plastic/metal</td>
<td>8.5x8.5</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>Stair case</td>
<td>F</td>
<td>reused onsite</td>
<td>timber</td>
<td></td>
<td></td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Stair handle [m]</td>
<td>8.4</td>
<td>E</td>
<td>reused onsite</td>
<td>timber</td>
<td></td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Stairs nosings</td>
<td>80</td>
<td>F</td>
<td>WC</td>
<td>plastic</td>
<td></td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Toilet</td>
<td>2</td>
<td>G</td>
<td>WC</td>
<td>ceramic</td>
<td></td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Toilet paper dispenser</td>
<td>3</td>
<td>G</td>
<td>WC</td>
<td>plastic</td>
<td></td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Toilet sink</td>
<td>3</td>
<td>G</td>
<td>WC</td>
<td>ceramic</td>
<td></td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Wall paper</td>
<td>calculate</td>
<td>P</td>
<td>WC</td>
<td>woodchip/paper</td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wall tiles</td>
<td>158</td>
<td>G</td>
<td>WC</td>
<td>ceramic</td>
<td>14x14</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Window frame</td>
<td>7</td>
<td>G</td>
<td>XX reused onsite</td>
<td>timber</td>
<td></td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Window glass</td>
<td>7</td>
<td>G</td>
<td>XX reused onsite</td>
<td>glass</td>
<td></td>
<td>Y</td>
<td></td>
</tr>
</tbody>
</table>
Subject: Site visit 5, alone
- sunny day, went there after having lunch in the vegan place on Marchmont st.
- went there without notice, [Personal name 78] was there, I walked around alone
- [Personal name 78] said they would finish by July
- plasterboard has been installed in basement walls and ceilings -probably on the other floors too, as ceiling was painted here I couldn’t notice it there were new plasterboards -I could see however that there was interstitial insulation (denim) above the ceiling.
- toilet cisterns were installed
- Floorboards were almost completely sanded on 4th floor
- Almost all ceilings and walls were painted with a brownish colour
- Electrical cabling was installed

For next visit:
Focus on REUSED components:
- COUNT
  - Windows (frame and glass)
  - Wardrobe doors
  - Partitions walls
  - Ceiling plasterboards
- MEASURE width of Floorboards

11 April 2017
Code: CS2_08
Subject: Site visit 6, talked with [Personal name 78] at IoE
Talked with [Personal name 78] at IoE, then he gave me a quick tour

From conversation with [Personal name 78]
- Project will be finished at end of May
- MFA > [Personal name 78] will put me in contact with [Company name 29]. He says they could give me details information on what they do with all the waste they get.
- LCA > [Personal name 78] says it would be possible to gather this information but would take time (SKA evidence could help)
- Specification > he showed me what he had (a list of items referenced in another booklet with more details on it) -He said he will send me the OMM (Occupations and Maintenance Manual) in one month, which contains all the information.

On components reuse:
- Floorboards
- Staircase
- Doors (x8)
- Door frames (80%)
Appendices

- Window & window frames (all but one)
- Partitions (all but two: 3rd floor toilet and GF kitchen, as far as I know)

*all items were reused for heritage criteria except for the floorboards

Ceiling was not removed, new ceiling plasterboard was installed under the ceiling in LG with acoustic insulation in between

Lightbulbs were not send to [Company name 29] but to other waste contractor named LCWR or something.

Next steps:

<table>
<thead>
<tr>
<th>Count</th>
<th>Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Windows (and frames)</td>
<td>Floorboards</td>
</tr>
<tr>
<td>Wardrobe doors</td>
<td>Wardrobe doors</td>
</tr>
<tr>
<td>Partition walls</td>
<td>Doors</td>
</tr>
<tr>
<td>Shelves</td>
<td></td>
</tr>
<tr>
<td>Staircases</td>
<td>Staircases</td>
</tr>
</tbody>
</table>

Ask [Company name 33] to put me in touch with design group ([Company name 18]) or send them email directly (ce’ing [Company name 33]; I don’t think they had a sustainability person? > I need the specification matrix. [Company name 42] one was very comprehensive (Element, Supplier, Recycled content, Lifespan, Reuse/Recycle, Embodied carbon factor, Transportation [km])

05 May 2017
Code: CS2_09
Subject: Site visit 7, Confucius Institute

I walked around by myself -took measures of doors and other components

Count:
- Windows: LG>4  GF>5  1st>3  2nd>3  3rd>4  total=19
- Doors: LG>7  GF>5  1st>2  2nd>4  3rd>4  total=22
- Wardrobe doors: GF>1  2nd>1 + two shelves total=2 (might had been more)
- Partitions: 1st>1  2nd>1  3rd>1  total=3
- Staircases: 46 + 16 (to 3rd floor) + 14 (to LG)  total=76

Measures [cm]:
- Floorboards: 1st>16 wide  else>21-23 wide, length varies
- Staircases: 28 x 94
- Doors dimensions [cm]:

<table>
<thead>
<tr>
<th>Lower Ground</th>
<th>Ground Floor</th>
<th>1st Floor</th>
<th>2nd Floor</th>
<th>3rd Floor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Door 1 81 x 200</td>
<td>88 x 211</td>
<td>94 x 213.5</td>
<td>82.5 x 202</td>
<td>75 x 190</td>
</tr>
</tbody>
</table>
Sent an email to [Personal name 78] if [Company name 29] hasn’t replied by next week

**27 June 2017**  
**Code:** CS2_10  
**Subject:** Site visit 8, after fit-out

Pictures are in folder.

[Personal name 81] (UCL Capital Projects Team Leader) was kindly waiting for me at the door to show me around the site. [Personal name 78] was inside waiting for her apparently.

The site looks very nice. They salvaged most of the floorboards and no floor covering was installed. They also salvaged the tiles in the three chimneys, all windows, ceiling, stair fence, etc.

Valerie gave me a booklet they created (some studio did) to introduce the IOE Confucius Institute.

**15 December 2017**  
**Date:** Code: CS2_11  
**Subject:** Questions about waste collection to [Personal name 78]

Hi [Personal name 78]

I hope all is well.

I have a few quick questions about the waste collection process at Confucius project. I know well how busy you are but I really need your support. I’ll try to be and concise as I can.

1) Did [Company name 29] load the wheelie bins in the compactor (including the bins themselves) or only the content of the bins was loaded?  
Reply: The bits are emptied in to the compactor

2) From the SWMP, I can see that [Company name 29] would collect different waste streams on one day (e.g. on 31st May: concrete, wood, metals, plasterboard... were collected). I can think of two options:

The bins at Confucius site contained pre-segregated waste

or
Appendices 292

[Company name 29] collected everything as mixed waste, and after segregation on their transfer site they provided figures for segregated waste. Reply: A bit of Both we segregated where possible and the rest they did in their yard.

3) [Company name 11] shows a lower level of segregation, did they use the same procedure for waste collection or was anything different? Reply: They used the same methods, there was a lot of different elements which all went away.

Many thanks for your kind support! I wish you happy holidays.

D.3.4 UCL Central House

Summary

- Main contact: [Personal name 20] (UCL project manager) <[personal email]>, [Personal name 24], [Personal name 21] ([Company name 33] site manager) <[personal email]>, [Personal name 33] (Architect) <[personal email]>
- 05-06-2017 -I emailed [Personal name 20], introducing me again and asking where the strip-out works will start.
- 08-06-2017 -[Personal name 20] replied suggesting I attend the build-up meeting before the project goes to tender.
- 17-07-2017 -I emailed [Personal name 20] to ask whether there’s a meeting scheduled yet.
- 04-09-2017 -I attended a Design meeting at Bidborough house -nothing relevant for me was discussed -see report -didn’t get a chance to talk to [Personal name 78] or [Personal name 20] personally.
- 12-09-2017 -I emailed [Personal name 20] and [Personal name 78] -[Personal name 78] replied shortly cc’ing [Personal name 21] ([Company name 33]) to ask if I could drop by and do Pre-Reburishment Audit.
- 19-09-2017 -I emailed them again to remind them.
- 19-09-2017 -Site visit 1: I got no answer so I popped down the site and introduces myself to [Personal name 21] -I did an inventory and took many pictures
- 19-09-2017 -I emailed [Personal name 20] asking where the furniture is -I emailed [Personal name 33] asking for floor plans and pictures before strip-out.
- 19-09-2017 -[Personal name 20] emailed [Personal name 18] (UCL Estates Strategy Manager) asking if he has an inventory -[Personal name 18] replied saying he also had a word with [Personal name 24] and would like to meet next week.
- 21-09-2017 -[Personal name 33] asked [Personal name 20] if she could share the plans and then sent them to me along with pictures of site before start.
- 04-10-2017 -I emailed [Personal name 24] asking to contact [Personal name 18] again -I will meet tomorrow with [Personal name 18].
- 05-10-2017 -I had a meeting with [Personal name 18] at Bidborough house, he seems nice. I must email him asking cost of storage at UCL.
- 06-10-2017 -I emailed [Personal name 18] asking for cost of storage, he hasn’t replied.
- 11-10-2017 -I emailed [Personal name 21] asking if he could meet to catch up on the project.
• 25-10-2017 -I had a meeting with [Personal name 21] based on a questionnaire I made.
• 22-11-2017 -I went for a site visit and took some pictures.
• 05-12-2017 -I emailed [Personal name 21] to see if we can have a catch-up meeting.
• 07-12-2017 -[Personal name 21] and I had a quick chat in which we went over through the steps of the re-fit.

04 September 2017
Code: CS3_01
Subject: First meeting – Pre-start meeting / Design stage

Meeting took place at Bidborough House room 305.

There were 12 attendees, mostly men in shirts (some ties) and two women, all sitting in a rectangular table.

Attendees I identified (check Project Board Meeting Minutes for a list of attendees):

• [Personal name 80], External Project Manager, 50s, bold, glasses, seating in front of me
• [Personal name 76], UCL Sponsor, 40s, bold, whitish beard, glasses, to my left, asked my name as I was sitting down
• [Personal name 71], UCL Stakeholder, 50s, blonde woman
• [Personal name 20], UCL UPO, 40s, curly-ish hair, seating next to [Personal name 71]
• [Personal name 33], [Company name 24] Architect, 40s, polish
• [Personal name 30], green eyes, a bit of beard
• [Personal name 73], guy with tattoo and strong arms (looks like he works on site)

*Guy to my right and [Personal name 71] spoke the most

Times:
• Start: 11-09-2017  > strip-out starts here
• End: 01-12-2017  *[Personal name 80] said they should wrap up by Christmas

[Company name 33] is already assigned as contractor.

Design issues they talked about:

1. Fixed vs moveable seating > want moveable, [Personal name 33] will send pictures of seating
2. Timber battens on wall: affect AV screens and the capacity to pin stuff > want a flat wall -Railing system and magnetic wall was mentioned as possibility
3. Gray paint instead of black
4. Carpet: [Personal name 33] showed us three Desso samples > [Personal name 71] said it’s better to use something already installed at UCL for ease-of-maintenance purposes *apparently they will used the gray sample as it’s already been used at Torrington Place project
5. Seating in the break-out area: [Personal name 33] showed us renders of sofa-beds > want moveable and with integrated power - [Personal name 71] will check what’s already installed at Torrington.
6. AV design > will reduce the shutters in order to fit the Audio-Visual screen
7. Signage: they want to make UCL more graphic > want to avoid having graphics too big that occupy much of the wall
8. Doors and escape routes > doors will automatically unlock in case of emergency, besides having a green box to open them manually

**On Finishes pack:**
- Sona Spray Acoustic for ceilings are ok [this is actually a tile, not a spray]
- AV company will come to install after contractor is done -there was a discussion on who should install the electrical circuits (or loop)
- Colour in break-out area should be grayish/whitish
- Exposed services should be galvanised or the same colour as wall/ceiling paint? [did not conclude]

**On other issues:**
- Glare control: [Personal name 33] mentioned the possibility of having electrical blinds or blackout blinds - [Personal name 30] said blackout is not required for any academic activity - [Personal name 30] also said blackout windows can get stuck as these are openable windows - Guy to the left of [Personal name 76] said the windows are not facing so not so much protection is needed
- Lighting control: [Personal name 30] said there should be lighting control per every space (e.g. blackboard, seating, etc.) - Light fittings should be ‘focused’ not to ‘spill’ light out of these spaces

19 September 2017
Code: CS3_02
Subject: Site visit 1 at Central House, pre-refurbishment audit

Date started: 11-09-2017

Date finished (estimated): Christmas 2017

Site manager: [Personal name 21] ([Company name 33]) <[personal email]>

UCL Project Manager: [Personal name 20] <[personal email]>

External Project Manager: [Personal name 80] <[personal email]>

Architect: [Personal name 33] <[personal email]>

Fit-out contractor: [Company name 33]

Strip-out contractor: [Company name 11]

GFA: *must enquire or calculate

Waste tickets: none yet
Process: 1) furniture, 2) carpet, 3) ceiling tiles, light fittings and services, 4) doors 5) building works (partitions).

Outgoing and retained components:

<table>
<thead>
<tr>
<th>Removed</th>
<th>Retained</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plasterboard partitions</td>
<td>7 doors (wardrobe)</td>
</tr>
<tr>
<td>Glazed partitions</td>
<td>HVAC units maybe?</td>
</tr>
<tr>
<td>Carpet tiles</td>
<td>Windows and window frames</td>
</tr>
<tr>
<td>Doors</td>
<td>Raised access flooring</td>
</tr>
<tr>
<td>Door frames</td>
<td>Items in toilet (probably)</td>
</tr>
<tr>
<td>Ceiling tiles</td>
<td></td>
</tr>
<tr>
<td>Ceiling rails</td>
<td></td>
</tr>
<tr>
<td>Furniture</td>
<td></td>
</tr>
<tr>
<td>Services: electrical and HVAC</td>
<td></td>
</tr>
<tr>
<td>Light fittings</td>
<td></td>
</tr>
</tbody>
</table>

Count of components:

<table>
<thead>
<tr>
<th>Item</th>
<th>Number of items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blinds {one per window}</td>
<td>22</td>
</tr>
<tr>
<td>Carpet tile [m2]</td>
<td>*CALCULATE</td>
</tr>
<tr>
<td>Ceiling tile +20 in toilet</td>
<td>469+20</td>
</tr>
<tr>
<td>Ceiling insulation pad</td>
<td>469+20</td>
</tr>
<tr>
<td>Ceiling tile rails [m]</td>
<td>582 *+perimeter</td>
</tr>
<tr>
<td>Door (timber)</td>
<td>6</td>
</tr>
<tr>
<td>Door (glazed)</td>
<td>3</td>
</tr>
<tr>
<td>Door (wardrobe) 7+1</td>
<td>8</td>
</tr>
<tr>
<td>Fire alarm</td>
<td>5</td>
</tr>
<tr>
<td>Fire extinguisher</td>
<td>2</td>
</tr>
<tr>
<td>Floor outlet (square-big)</td>
<td>6</td>
</tr>
<tr>
<td>Floor outlet (round)</td>
<td>40</td>
</tr>
<tr>
<td>Furniture (workstations)</td>
<td>*FIND OUT</td>
</tr>
<tr>
<td>Furniture (chairs)</td>
<td>*FIND OUT</td>
</tr>
<tr>
<td>Partitions (plasterboard)</td>
<td>2</td>
</tr>
<tr>
<td>HVAC ductwork</td>
<td>*FIND OUT</td>
</tr>
<tr>
<td>Partitions (glazed)</td>
<td>1</td>
</tr>
<tr>
<td>Light fitting (square-big)</td>
<td>72</td>
</tr>
<tr>
<td>Light fitting (round)</td>
<td>9</td>
</tr>
<tr>
<td>Raised access flooring [m2]</td>
<td>*CALCULATE AREA</td>
</tr>
<tr>
<td>Socket</td>
<td>14</td>
</tr>
</tbody>
</table>

Toilets

| Dispenser (paper)                  | 3               |
| Dispenser (soap)                   | 2               |
| Dryer                              | 1               |
| Heater                             | 1               |
| Sink                               | 3               |
| Toilets                            | 3               |
| Urinals                            | 3               |
### Measures of components:

<table>
<thead>
<tr>
<th>Item</th>
<th>Dimensions of item [cm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carpet tile</td>
<td>50 X 50</td>
</tr>
<tr>
<td>Ceiling tile</td>
<td>59.5 X 59.5</td>
</tr>
<tr>
<td>Door (timber)</td>
<td>91.5 X 203 (2), 92.5 X 203</td>
</tr>
<tr>
<td>Door (glazed)</td>
<td>105 X 214 (2)</td>
</tr>
<tr>
<td>Floor outlet (square-big)</td>
<td>23 X 36.5</td>
</tr>
<tr>
<td>Floor outlet (round)</td>
<td>15 diameter</td>
</tr>
<tr>
<td>Partition (plasterboard)</td>
<td>246 X 365, 246 X 262, 246 X 160 (2)</td>
</tr>
<tr>
<td>Partition (glazed)</td>
<td>246 X 345</td>
</tr>
<tr>
<td>Socket</td>
<td>8.5 x 14.5 *MEASURE</td>
</tr>
</tbody>
</table>

### Collated table:

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Quality</th>
<th>Destination</th>
<th>Waste stream</th>
<th>Dimensions [cm]</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blinds {one per window}</td>
<td>22</td>
<td>F</td>
<td>WC</td>
<td>plastic/textile</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Cable: electrical [m]</td>
<td>*CALC</td>
<td>G</td>
<td>WC</td>
<td>plastic/metal</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Cable: ethernet [m]</td>
<td>*ASK</td>
<td>G</td>
<td>WC</td>
<td>metal/plastic</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Carpet tile [m2]</td>
<td>*CALC</td>
<td>G</td>
<td>WC</td>
<td>plastic/textile</td>
<td>50 x 50</td>
<td></td>
</tr>
<tr>
<td>Ceiling tile (+20 in toilet)</td>
<td>469+20</td>
<td>E</td>
<td>WC</td>
<td>metal</td>
<td>59.5 x 59.5</td>
<td>20 in toilet, these get easily damaged when removing</td>
</tr>
<tr>
<td>Ceiling insulation pad</td>
<td>469+20</td>
<td>E</td>
<td>WC</td>
<td>insulation</td>
<td>59.5 x 59.5</td>
<td>20 in toilet</td>
</tr>
<tr>
<td>Ceiling tile rails [m]</td>
<td>582+per</td>
<td>E</td>
<td>WC</td>
<td>metal</td>
<td>-</td>
<td>Add GFA perimeter</td>
</tr>
<tr>
<td>Door: timber</td>
<td>6</td>
<td>E</td>
<td>WC</td>
<td>wood</td>
<td>105 x 204</td>
<td></td>
</tr>
<tr>
<td>Door: glazed</td>
<td>3</td>
<td>E</td>
<td>WC</td>
<td>glass/metal</td>
<td>varies</td>
<td></td>
</tr>
<tr>
<td>Door: wardrobe</td>
<td>8</td>
<td>E</td>
<td>RET</td>
<td>wood</td>
<td>?</td>
<td>7+1(in front toilet)</td>
</tr>
<tr>
<td>Fire alarm</td>
<td>5</td>
<td>G</td>
<td>WC</td>
<td>metal/plastic</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Item</td>
<td>Quantity</td>
<td>Quality</td>
<td>Destination</td>
<td>Waste stream</td>
<td>Dimensions [cm]</td>
<td>Comments</td>
</tr>
<tr>
<td>---------------------------</td>
<td>----------</td>
<td>---------</td>
<td>-------------</td>
<td>--------------</td>
<td>----------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>Fire extinguisher</td>
<td>2</td>
<td>E</td>
<td>RET</td>
<td>Metal</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Floor outlet: round</td>
<td>40</td>
<td>E</td>
<td>WC</td>
<td>plastic</td>
<td>15 (ø)</td>
<td></td>
</tr>
<tr>
<td>Floor outlet: square</td>
<td>6</td>
<td>E</td>
<td>WC</td>
<td>plastic</td>
<td>23 x 36.5</td>
<td></td>
</tr>
<tr>
<td>Floor outlet: socket</td>
<td>12</td>
<td>G</td>
<td>WC</td>
<td>metal/plastic</td>
<td>8.5 x 14.5</td>
<td>Inside square outlet</td>
</tr>
<tr>
<td>Furniture: workstations</td>
<td>*ASK</td>
<td>E</td>
<td>ROF</td>
<td>metal/wood?</td>
<td>?</td>
<td></td>
</tr>
<tr>
<td>Furniture: chairs</td>
<td>*ASK</td>
<td>E</td>
<td>ROF</td>
<td>plastic/textile?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HVAC ceiling cassettes</td>
<td>*COUNT</td>
<td>E</td>
<td>ROF</td>
<td>metal/plastic</td>
<td>?</td>
<td></td>
</tr>
<tr>
<td>HVAC ductwork</td>
<td>*ASK</td>
<td>E</td>
<td>WC</td>
<td>metal</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Light fitting: square</td>
<td>72</td>
<td>E</td>
<td>WC</td>
<td>metal/plastic</td>
<td>?</td>
<td></td>
</tr>
<tr>
<td>Light fitting: round</td>
<td>9</td>
<td>E</td>
<td>WC</td>
<td>metal/plastic</td>
<td>?</td>
<td></td>
</tr>
<tr>
<td>Light tube</td>
<td>216</td>
<td>G</td>
<td>WC</td>
<td>glass/metal</td>
<td>57.5</td>
<td></td>
</tr>
<tr>
<td>Light bulb</td>
<td>9</td>
<td>G</td>
<td>WC</td>
<td>glass/metal</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Partition: glazed</td>
<td>1</td>
<td>E</td>
<td>WC</td>
<td>glass</td>
<td>246 x 345</td>
<td></td>
</tr>
<tr>
<td>Partition: plasterboard</td>
<td>4</td>
<td>E</td>
<td>WC</td>
<td>gypsum</td>
<td>varies</td>
<td></td>
</tr>
<tr>
<td>Raised access flooring [m²]</td>
<td>*CALC</td>
<td>E</td>
<td>RET</td>
<td>metal</td>
<td>61 x 61</td>
<td></td>
</tr>
<tr>
<td>Socket: electrical</td>
<td>14</td>
<td>G</td>
<td>WC</td>
<td>metal/plastic</td>
<td>8.5 x 14.5</td>
<td></td>
</tr>
<tr>
<td>Toilet</td>
<td>3</td>
<td>E</td>
<td>RET</td>
<td>ceramic</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Item</td>
<td>Quantity</td>
<td>Quality</td>
<td>Destination</td>
<td>Waste stream</td>
<td>Dimensions [cm]</td>
<td>Comments</td>
</tr>
<tr>
<td>--------------------------</td>
<td>----------</td>
<td>---------</td>
<td>-------------</td>
<td>--------------</td>
<td>----------------</td>
<td>----------</td>
</tr>
<tr>
<td>Toilet paper dispenser</td>
<td>3</td>
<td>E</td>
<td>RET</td>
<td>plastic</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Toilet soap dispenser</td>
<td>2</td>
<td>E</td>
<td>RET</td>
<td>plastic</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Toilet dryer</td>
<td>1</td>
<td>E</td>
<td>RET</td>
<td>metal/plastic</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Toilet heater</td>
<td>1</td>
<td>G</td>
<td>RET</td>
<td>metal</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Toilet sink</td>
<td>3</td>
<td>E</td>
<td>RET</td>
<td>ceramic</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Toilet urinals</td>
<td>3</td>
<td>E</td>
<td>RET</td>
<td>ceramic</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Window frame</td>
<td>22</td>
<td>G</td>
<td>RET</td>
<td>metal</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Window pane</td>
<td>22</td>
<td>G</td>
<td>RET</td>
<td>glass</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

Newly installed (mentioned by [Personal name 21]):
- Services
- Timber panels on doors and AV screens
- Plant room (for natural ventilation)

To do:
- Ask about cable
- Find out about furniture
- Open up insulation

25 October 2017
Code: CS3_03
Subject: Central House site visit, Interview with Site Manager – [Personal name 21] ([Company name 33])
1. What is the project’s GFA?
Doesn’t have the figure off the top of his head, will get back to me.

2. What have been the steps in the strip-out process? e.g. >
   1. Furniture [workstations, chairs, lockers, shelves]
   2. Floor finishes [carpet]
   3. Doors
   4. Ceiling tiles/insulation and Light fittings
   5. Ceiling tiles rails -called metalwork
6. Services [HVAC ductwork, cabling]
7. Sockets, Outlets and Fire alarms? -fire alarms are still in
8. Raised access floor -RAF is retained, just a few are replaced> the ones with holes or that used to have outlets
9. Internal partitions -the slab-to-slab partitions come out last, but the raised-floor-to-ceiling partitions come first
10. Blinds -blinds are still in but will get eventually replaced. [Personal name 21] says they left them in because they don’t obstruct the works

2. Was [Company name 11] in charge of taking their own waste? [Y/N]  
   Yes, they have their own carrier license and they take the waste to a transfer station and provide a waste ticket *[Personal name 21] can provide a copy of a [Company name 11] waste ticket

3. How was the process for waste collection? e.g.>
   1. Mixed waste is put in the skips/bins
   2. Lorry comes by the back door
   3. Skips are loaded on the lorry OR only skips’ content is loaded [is waste mixed in the lorry?] 
   The process is right. Only the skip/bin content is loaded and waste is mixed in the lorry.

4. During fit-out, how will the process for waste collection be?  
The process will be similar. Mixed waste is put in bins, then a cage wagon or a compactor takes the waste.

5. Is there a way of knowing the amounts of different waste?  
The waste contractor provides recycling figures at the end of the project. However, the waste generated in this project is put together with waste from other projects. [Personal name 21] says this is because the scale of the project is small. A large project would probably require its own compactor.

6. When will the fit-out (re-fit) start?  
The fit-out stage has begun now. They are:
   1. Cleaning the underfloor > they are cleaning because they will use this plenum (space) to circulate fresh air that will come out through the floor. This air will be pumped through an air-handling unit. The air is taken from outside, pressurised and then
pumped to the plenum. [Personal name 21] mentioned they will add a coat of sealing
[I’m assuming on top?]

2. First fix of services (next week)
3. Metalwork for suspended ceilings
4. Acoustic spray (on Monday)
5. First fixed partitions

7. Where any of these items reused onsite/offsite or retained?
   - HVAC cassettes > probable offsite reuse at UCL - [Personal name 21] says whatever
good components they find, they send an email to UCL letting them know the corre-
spending components are available for reuse. UCL has provide no answer regarding
the cassettes. [Company name 33] is keeping the on one side in the meanwhile.
   - Glazed doors > they couldn’t reuse them for anything
   - Timber doors > reused where possible. [Personal name 21] says about 50% are being kept
   - Raised access floor > retained
   - Fire extinguisher > retained
   - [Personal name 21] says some OCM (light controls) are also being kept

8. In your opinion, why do you think useful components in good condition [socket, light
fitting, ceiling/carpet tiles, ductwork] are not kept or sold for reuse? [due to space, time, cost-benefit?]
   - First, this has to do with the cost-benefit as you have to transport, store, remove and reinstall the items. Sometimes the cost of reusing exceeds the cost or replacement.
   - Other reason is that items might be out of date. [Personal name 21] mentioned the example of some light tubes.
   - Lastly, the design is important - people want new-
   - For the case of the carpet tiles: they were dirty (coffee stains), didn’t look new, and they sometimes distort when removed and don’t fit precisely when reinstalled [I disagree as I saw most carpet tiles were in fair conditions]. The new carpets installed (manufactures by Milliken) will have acoustic properties.
   - Space is another reason: [Personal name 21] mentioned that if UCL kept all reusable items they would soon fill up a Wembley Stadium.
## Procedure for fit-out (or re-fit):

<table>
<thead>
<tr>
<th>Elements to consider</th>
<th>Order</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acoustic spray on ceiling</td>
<td>2</td>
<td>One of the first</td>
</tr>
<tr>
<td>RAF maintenance work</td>
<td>1</td>
<td>Steps below¹</td>
</tr>
<tr>
<td>Underfloor cabling/services</td>
<td>1</td>
<td>Not a great deal</td>
</tr>
<tr>
<td>Drylining (plasterboard+insulation?)</td>
<td>3</td>
<td>old plasterboard removed? any stud?²</td>
</tr>
<tr>
<td>Internal partitions</td>
<td>3</td>
<td>This is part of the drylining</td>
</tr>
<tr>
<td>Air-handling unit</td>
<td>4</td>
<td>Was designed and brought all together, they had to break it down in order to get it in</td>
</tr>
<tr>
<td>Wall finishing (paint?)</td>
<td>5</td>
<td>Paint will be added, they put a sealer layer plus three layers of paint³</td>
</tr>
<tr>
<td>Ceiling cabling</td>
<td>4</td>
<td>They first installed the cabling containment, which can be tray or basket. They're using trays</td>
</tr>
<tr>
<td>HVAC cassettes</td>
<td>4</td>
<td>New ones are installed</td>
</tr>
<tr>
<td>HVAC ductwork</td>
<td>4</td>
<td>This is contained within the plantroom⁴</td>
</tr>
<tr>
<td>Light fittings</td>
<td>6</td>
<td>They are late (at the late stages)</td>
</tr>
<tr>
<td>Electrical sockets</td>
<td>6</td>
<td>At the end (called 2nd fix work)</td>
</tr>
<tr>
<td>Fire alarms</td>
<td>6</td>
<td>Same as above</td>
</tr>
<tr>
<td>Floor finishing (carpet?)</td>
<td>7</td>
<td>At the very end</td>
</tr>
<tr>
<td>Doors</td>
<td>7</td>
<td>Late items</td>
</tr>
<tr>
<td>Window blinds</td>
<td>7</td>
<td>At the very end, these will be inside rather than in-between window panes</td>
</tr>
</tbody>
</table>

### Project GFA? > send email

Could you refer me to someone I could contact at [Company name 11]? > [Personal name 21] says [Personal name 89] is the owner/director, [Personal phone number]

¹Steps of RAF works
1. Reduce redundant services
2. Install new services
3. Floor is sealed (on the substrate/concrete) so it’s dust free
4. Floor goes back on
5. Level and de-rock
6. Carpet/floor finishings installed

2Plasterboard
Some drylining is new and some was retained. In general partition walls were removed and new ones installed while bearing walls retained the old drylining. There is a new partition installed where the air handling unit is installed, and a partition was installed in the middle of the site, dividing the two rooms (I think the former dividing partition was removed).

Where new partition walls are installed, they’re being installed from slab to slab (rather than from RAF to slab) for acoustic and fire-safety reasons. Likewise, when a new partition wall intersects with an old wall, the new one is inserted in the old one in order to prevent air flow and thus sound flow. [Company name 33] uses a steel stud, with one plasterboard layer on the outside, three layers on the inside (where a final paint layer will be added), and the cavity is filled with mineral wool. EC says they’re using three layers for acoustic purposes. Finally, they tape and joint the plasterboards before being sealed and painted.

[Personal name 21]: I can check the ‘British Gypsum White Book’ which is a guide to finding solutions using British Gypsum products.

3They use three layers of paint for the following reason. The two first layers are two cover up properly. The last layer is done under the final lighting conditions (once light fitting are installed) in order to see the quality of the work (and the brushes) as it actually looks under the actual lighting.

4They ductwork is contained within the plantroom, where the air-handling unit (AHU) is located. The AHU will deliver the fresh (or heated) air through the floor plenum (the cavity under the RAF). They installed 36 grills on the floor through where the air will come out. Stale air will be absorbed (somewhere in the ceiling) and taken back to the AHU. The AHU is connected to an outside inlet where fresh air comes in and an outlet where stale air goes out.
Extra: Speaking or services, there is high-level (ceiling) and low-level work (floor), which are carried out depending on procurement. The low-level work is carried out after RAF is installed (opening up the corresponding RAF to install services), so that RAF protects the services.

D.3.5 Conduit Members’ Club

Summary

- Main contact: [Personal name 60] ([personal email]), [Company name 49]
- 21-03-2017 - Met with [Personal name 60], [Personal name 68] (the client), and Ben Croxford at the site. We spoke for 15 mins in a room and then we went to see three or four floors of the site. *it is pending to download pics -there were: carpet, marble floor, marble wall, chandelier, ceiling tiles, light fittings, lots of chairs, some tables
- 22-03-2017 -[Personal name 60] sent mail to [Personal name 63] asking permission for us to their dropbox folder containing the tracker (list of components on-site).
- 26-04-2017 -[Personal name 60] sent me a link with the tracker for items (pre-defit audit)
- 09-06-2017 -I came on-site for the first ‘Open day’ in which interested buyers/takers would come to see what is for sale/giving away -I stayed from 10:00 to 16:30 -No one came, but [Personal name 52] and [Personal name 60] updated the tracker (spreadsheet), by adding photos and price (when sold).
- 05-07-2017 -I came to the second Open Day where around four parties (comprised of around then people) attended -see report.
- 24-07-2017 -I attended a project meeting, post Open Day.
- 05-09-2017 -[Personal name 60] sent an email to [Personal name 57] ([Company name 22]) to advise me when I can go onsite and watch the strip-out process.
- 12-09-2017 -I emailed [Personal name 60] and [Personal name 57] to remind them about my visit.
- 14-09-2017 -[Personal name 60] wrote me inviting me for a site visit next Wednesday 20th.
- 19-09-2017 -Site visit during strip-out: [Personal name 57] showed me around and explained the process -see report.
- 21-09-2017 -I emailed [Personal name 60] asking a few follow-up enquiries.
- 11-10-2107 -I emailed [Personal name 60] to remind her about the enquiries.
- 01-11-2017 -[Personal name 60], [Personal name 52] and I met at Ole&Sten café where we had a one-hour chat. They liked my supply chain diagram and helped edit it. We also went through the procedure for the salvaging of components -I later sent then a draft and they sent me their comments in the following weeks.
- 10-07-2018 -I emailed [Personal name 60] asking for a catch-up meeting and the SWMP.

21 March 2017
Code: CS4_01
Subject: Site visit 1 to The Conduit (hotel/club)

The client: [Personal name 68]

Sustainability consultant: [Company name 49] ([Personal name 60])
Met with [Personal name 60], [Personal name 68] (the client), and Ben Croxford at the site. We spoked for 15 mins in a room and then we went to see three or four floors of the site. *it is pending to download pics -there were: carpet, marble floor, marble wall, chandelier, ceiling tiles, light fittings, lots of chairs, some tables

They will start mayor defit at end of August

The works are due to be finished on September 2018

They’re aiming to carry out an LCA on the project.

On 19-04-2017 [Personal name 60] ([Personal name 63] cc’d in) shared a bunch of documents through Dropbox: [web address]

On 26-04-2017 -[Personal name 60] sent me a link with the tracker for items (pre-defit audit): [web address]

*[Personal name 60] mentioned she doesn’t trust recycling facilities rates.

**09 June 2017**
**Code: CS4_02**
**Subject: Meeting at Conduit Project**

Attendees: [Personal name 60] and [Personal name 52]

Dropbox link: [web address]

The list was uploaded on wed afternoon… so people really just had one day to check out the items to be sold/given away. Still 16 people sent a request. 3 of them are poping up today, 1 of them has a charity.

[Personal name 52] y says they’re mostly interested in the ceiling tiles, [Personal name 60] was surprised

More will come on the 5th

Globechain normally don’t sell items (freecycle), but this time they will try selling some of the stuff

People that might come today are coming for: ceiling tiles, toilet, wood flooring, marble flooring

[Personal name 60]: how you tell what stuff is, e.g. is this marble floor or stone?, or is this furniture maple or something else?

[Personal name 68] came in later, he asked what would happens if the buyers/takers come and try to remove something (e.g. marble flooring) and when they realise it’s too difficult or it’s breaking they retract and don’t want it anymore.

[Personal name 60] answered, they are trying to avoid it but if it happens they would have to dispose (recycle) whatever is left.

1st August -> strip-out may start around then

A guy called Phoenix? will take care of the LCA and the energy modelling
*Remind Ben Croxford [Personal name 60] ask if there’s someone who might help with the energy modelling

**On other issues:**

Conduit is following no certification scheme, [Personal name 60] says because they don’t want to “be in a box”.

Reset certification plan -for wellbeing ->[Personal name 60] is probably carrying out a project to measure air quality in several buildings (in several countries) for a company -she asks if someone from my office would be interested in participating as part time job > answering phone calls, installing sensors (I guess).

05 July 2017

Code: CS4_03

Subject: Conduit project – Globechain Open Day 2

Attendees: [Personal name 52], [Personal name 60], [Personal name 37] ([Personal name 52]’s employee)

**Participants:**

At 10:00 there was a first tour for a group of four people, two African older woman and a guy

At 11:00 the second tour comprised, two black tall guys (Maynard), four older blonde women, a young guy in shorts

[Personal name 32], charity, wants everything -but [Personal name 52] will give a chance to the other guys

French charitable organisation

British Heart Foundation

Maynard, charitable organisation

**Process:**

Everyone get assigned a number (first come, first served), so they are given priority according to this number

Participants could reserve whatever they saw and wanted. [Personal name 60] called them according to their number and she would write down on a blank paper what they want

Participants are asked to remove stuff themselves (before mid August), along with an experienced (certified and insured) electrician or so -if they cannot/don’t want to remove it themselves, they can wait for the strip-out contractor and [Personal name 60] will ask how much the contractor would charge to carefully remove the respective items

**Interesting item:**

[Personal name 52] says people are mostly interested in: wooden flooring, metal ceiling panels

All the 2nd floor wooden floor
All the ceiling panels
All the doors
All the sockets and light fittings
Also, more specific interests:
Fan coils
Exist signs
Sockets
CCTV camera, and speakers
Some pillars (3 of them want 4 pillars), mirrors
Curtains and chandeliers

How to proceed from here:

Friday 6> [Company name 22] should come and quote the prices
Monday 10> by then should have confirmation of prices (which are supposed to be less than half price), meaning they can do it
Tuesday 11> define who’s getting what -could post some stuff on eBay from here
Thursday 14>
Friday 15> must confirm categorically that they are taking those items -if it’s for sell they have to pay by then
Sunday 30 > Strip-out whatever is not gone
An email will be sent to the participants to look at the attached spreadsheet, make sure they’re ok with paying the stated price or make an offer… Otherwise stuff will go to eBay
Whatever they don’t want will go on eBay
Namely, chandelier, staircase (need to check price), speakers, curtains (to see if they can get more money on eBay) >these should include the cost of being taken out
[Company name 22] takes over the place from 31st July
31 to 7 July> Strip out, maybe
17 to 31 August> participants can come take the things by themselves

Phase 2:
The top floors: glass panels, partitions, workstations and chairs

24 July 2017
Code: CS4_04
Subject: Meeting – Conduit project meeting 3 – Post open day
Attendees:
- [Personal name 60]
- [Personal name 52]
- Client’s health and Safety representative
- [Personal name 15], [Company name 22] Project Manager
- Another guy from [Company name 22]
- Architect (young guy and a woman)
- Another guy

[Personal name 15]: End of next week -due to strip out

[Personal name 60]: Spotchecks, follow the van -to see where the stuff is going

[Personal name 60]: East London Charity (ELC) -the most engaged

[Personal name 60]: McOllies electricians -he offered them three guys for as many days - whatever they can: sockets, light fittings, switches, speakers, chandeliers

**Wood** -2nd floor -looks like the wooden floor can be taken easily

Will evaluate Social impact hours -employing ex-convicts or teenagers off-rails

[Personal name 15]: price for stripout vs price for careful stripout

**Doors** – lots of interest on the doors -will take the out and stack them to be then collected

Guy new: **Doorframe** not as useful

[Personal name 15] -**glass panels** are difficult to take carefully (logistics)

Ceiling tiles: lots of interest -[Personal name 15]: whos taking those out? [Personal name 60]: [Personal name 32] from ELC didn’t want them -will split them between two persons

Guy to my left: Who’s going to supervise? [Personal name 60]: either ask [Company name 22] the cost to do it or arrange with takers

[Personal name 54] from Smartcom supposed to let her know how many can be retained or should go?

[Personal name 52]: speaks about a student of medicine who sells stuff to pay his school -he came and spot things nobody else saw -he might be able to sell the big chandelier (which didn’t go through eBay) -he says speakers might cost £1k new

No interest in commercial kitchens!

[Personal name 60] is going to look at charities’ paperwork next week

**Wood** is taken away whether is broken or not -the takers will try to reuse as much as possible

**Staircase** is being retained

**Ceiling tiles**: Maynard is taking them

**Marble wall**: British Heart Foundation is taking it

**Columns and mirror** in basement: TBC
[Company name 22] guy: all of this needs to be planned in order to work -he said this is something I should consider

Charities need to have contractors on board to remove stuff

Granite top of bar can be taken but is customised ([Personal name 60]) so what could you do with it?

My notes:

Relevant issues

- planning
- removal
- storing
- transport
- finding someone who wants the stuff

Coffee with [Personal name 52] ([Personal name 60] just left):

Charities need to provide: Risk assessment and methods statement

Attendees:

They guy next to me is the Health and Safety representative for the client

Two guys from [Company name 22] ([Personal name 15] and the bald guy next to him who talked about planning)

Architect

19 September 2017
Code: CS4_05
Date: Site visit 2 – during strip-out, with [Personal name 57]

Sustainability consultant: [Company name 49] ([Personal name 60])

Reuse platform: Globechain ([Personal name 52])

Fit-out contractor: [Company name 22] ([Personal name 57])

Strip-out contractor: [Company name 10]

Waste contractor: *must enquire

[Personal name 57] was introduced to me through [Personal name 60] -He is [Company name 22] site manager for Conduit project

[Personal name 57] (40s, rounded, healthy-looking face) was kind a patient to show me around the site and explain how the salvaging process is being carried out -He asked is I have a CSCS card (Construction Skills Certification Scheme)

About the project:

Building is 9 stories, including 6 floors, a mezzanine and basement.
Appendices

Strip-out started in level 3 as this was unoccupied

Strip-out is done by contractor [Company name 10]

Waste is not being segregated

The project is CCS registered -[Personal name 57] thinks this scheme is good

Project is to be finished on July 2018

**Overall strip-out process:**

1. Floor finishings
2. Partitions (non-load-bearing)
3. Suspended ceilings and raised access floor
4. Services (HVAC, MEP)

**Process of salvaging strip-out:**

There are three categories of building components to be removed:

- Nobody wants > go to waste contractor
- Onsite reuse > taken by [Company name 10] to their storage -then they will bring these back when it’s time to be re-installed -don’t keep these on site because of space issues and not to get damaged
- Offsite reuse (salvaged through Globechain) > carefully removed by [Company name 10], wrapped and palleted -then taken to the same storage and kept for 48 hours to be collected by Globechain takers*

*takers often delay to collect stuff and this delays the whole process because lack of space in [Company name 10] storage

Must consider that there is a transition from Building to Construction site -when it is construction site it is not feasible to audit or salvage stuff by others than strip-out contractor

In case stuff is removed by others, there must be a Principal Designer (also known as Health and Safety officer) who has a ‘duty of care’ to oversee stuff is removed and taken safely

First approach was to ask Charities what they want and how they will take it, however this didn’t work because:

- They were out of time
- They were unsure/dubious
- They are not enough knowledgeable to remove and transport the stuff properly

At the end, [Company name 10] had to remove the items for Globechain and store these in [Company name 10]’s storage (wrapped and palleted) -Globechain takers must go there within 48 hours to collect the items -after this time period, items should be taken to waste contractor

[Personal name 57] would send an email with pictures to [Personal name 60] and [Personal name 52], letting them know that the salvaged items are in storage and must be picked up on time

Some issues that came up with this system:
Items sometimes don’t look as good or appealing when they are removed
Some takers changed their mind

Strip-out package was determined initially to do things this way, with an additional cost embedded
Strip-out contractor had to take additional care when removing items -this implies more cost in time
Strip-out contract documents include: Colour-coded Floor plan showing in red items to be disposed, in yellow items to be reused onsite and in green items to be salvaged for Globechain takers; bill of quantities

Risks involved:

- Items can get damaged in transportation > provoking items working wrong (e.g. light fittings catching fire)
- There is a risk involved for [Company name 22] > they can be held accountable for the final destination of salvaged items
- Globechain needs to trace what happens with the items, confirm the charities are doing what they said -[Personal name 57] doesn’t know if this is taking place

On building components:

Fire doors are needed until finished -a fire route is necessary in case of emergencies
Raised Access flooring is going to waste contractor > it’s remaining life expectancy is below 5 years and the pedestals are not made anymore ([Personal name 57] says RAF usually have a life expectancy of 12 to 15 years)

Items with removability complications:

- Wooden floor > it is on timber battens on plywood -it is stock on the plywood -it is hard to separate in practice -the tiles that come off loosely are kept as spares for 3rd floor which will retain that type of flooring
- Marble wall (dived in four segments) > is glued to the wall and breaks when removed
- Glass partitions > cannot be taken out through the stairs because of their large size - will have to take the out through the window with a hoist (using the scaffolding outside)

[Personal name 57] recommendations on the process [when I prompted]:

- Do the most you can do at start
- Do the ‘open days’ timely
- Keep the fluency
- Recording and auditing is essential as the whole process relies on so many people: architect, sustainability consultant, fit-out contractor, strip-out contractor, waste contractor, Globechain, charities
- Maintain good communication among actors

Challenges:

- Space
• Fluency/time
• Removing the stuff without damaging
• Understanding different elements of strip-out package

Opinions:
• The concept is good
• There is a learning curve
• Can be carried out in further projects

Next steps:
Ask [Personal name 60] for
Colour-coded plans
Photos of wrapped, salvaged items: sockets, light fittings, carpet, ceiling tiles, blinds
Price difference charge by [Company name 10] in order to salvage items
All actors involved in the supply chain
GFA
Ask [Personal name 52] for:
How she is tracing the takers

01 November 2017
Code: CS4_06
Subject: Meeting with [Personal name 60] and [Personal name 52]
Project: Conduit Member’s Club
GFA?

Process of salvaging strip-out: [This is what I had written]

1. Inventory of on-site building components: Conduit Globechain-050717 post open day.
2. Components are offered on Globechain platform.
3. ‘Open days’ allow interested parties to come to site and view/reserve the components they want. Open days invitations are sent to potential ‘takers’ through email/Globechain platform?
4. All building components on site are coloured in the floor plans to indicate the corresponding pathway, as follows: green) offsite reuse, salvaged through Globechain; yellow) onsite reuse; and red) taken by waste carrier, which in this case is the strip-out contractor.
5. Components classified for onsite and offsite reuse are carefully removed, palletised and taken by the strip-out contractor to their storage site. Onsite-reuse items will be brought back to site when needed, while offsite-reuse items must be collected by Globechain takers within 48 hours.
6. When offsite-reuse components arrive to storage site, emails with photographs are sent to Globechain takers to notify items are available for pick-up.
[This is what [Personal name 60] suggested me to write]

12. [Company name 38] identified which products they want to reuse on the project
13. [Company name 38] marked what they want on the Demolition Plans
14. Globechain and Sustainability Consultant walked around, took photos and made a list
15. Both lists combined in what they called the Tracker, photos, dimensions and quantities when available, identified by floor and demolition stage
16. Items are listed on Globechain: items for free and items for sale (this was a test*)
   a. Listings clearly stated that some items would have to be removed professionally by the Recipient, complying with H&S requirements of the site
   b. Risk Assessments and Method Statements were also requested (NB, this proved to be problematic in reality)
17. Open days announced in the listing on Globechain platform
18. Recipients requested items and booked in for Open Day visits
19. Globechain and Sustainability Consultant walked Recipients around site
20. Recipients confirmed which items they wanted, and ability to remove items themselves
21. General Contractor is appointed (and highlights risk of untrained professionals removing fixed items from a working building and/or working construction site)

Plan B

1. Using Demolition Plans, Demolition Contractor strips out floor by floor.
2. Items coordinated and taken off site by Demolition Contractor to their yard in East London. Demolition Contractor notified Globechain and Sustainability Consultant which items were removed to the yard.
3. Items held at the yard for 2 days, otherwise landfill/waste removal charges were incurred.
4. Recipients (as above) advised that items were available for collection and removed these directly from the site. Globechain coordinated this process.
5. Recipients detail what they are intending to do with the items via the Globechain platform.
6. Globechain collects data on social, environmental and economic impact and available for Client to download.

Issues with takers:
- Some takers changed their mind
- Items sometimes don’t look as good or appealing when they are removed
- Takers delaying in picking up the components.

Removability complications:
- Wooden floor > it is on timber battens on plywood -it is stock on the plywood so it’s hard to separate in practice. The tiles that come off loosely are kept as spares for 3rd floor which will retain that type of flooring
- Marble wall (dived in four segments) > is glued to the wall and breaks when removed.
• Glass partitions > cannot be taken out through the stairs because of their large size - will have to take the out through the window with a hoist (using the scaffolding outside).

**On building components:**

• Fire doors are needed until finished - a fire route is necessary in case of emergencies
• Raised Access flooring is going to waste contractor > it’s remaining life expectancy is below 5 years and the pedestals are not made anymore ([Personal name 57] says RAF usually have a life expectancy of 12 to 15 years)

**Ask [Personal name 60] for:**

• Colour-coded plans
• Photos of wrapped, salvaged items: sockets, light fittings, carpet, ceiling tiles, blinds
• Price difference charge by [Company name 10] in order to salvage items
• All actors involved in the supply chain
• GFA
• Link to final Tracker

**Ask [Personal name 52] for:**

• How she is tracing the takers

**D.3.6 Other fit-out case studies**

**Summary**

**UCL Here East**

• Main contact: [Personal name 24], UCL
• Started March 2016
• 13-03-2016 - Went to a SKA scoping session in [Company name 18]'s Office
• 21-03-2017 - [Personal name 24], [Personal name 14] and I got together (Bidborough House) to do the SKA scoping in more detail

**UCL Bloomsbury Theatre**

• Main contact: [Personal name 24], UCL
• Started October 2016
• 11-11-2016 - Ska scoping BETA w/ [Personal name 14], [Personal name 9] and 9 more people in Bidborough House
• 15-11-2016 - Pre-refurbishment audit and waste management planning with [Personal name 14], [Personal name 9] and 9 more people at Bloomsbury Theatre

**UCL Torrington Place PhD Hub**

• Main contacts: [Personal name 77] <[personal email]>, [Company name 25] <[personal email]>, [Company name 41]
• 31-03-2017 - [Personal name 24] wrote to Tom asking to facilitate a meeting for me.
• 03-05-2017 - I wrote to Tom asking [Personal name 65] to share any data on waste.
• 15-05-2017 - I wrote to Tom and Rod (cc’ing Ben Croxford and [Personal name 24]) asking for a meeting or a site contact.

**UCL Institute of Education (IOE)**
Main contacts: [Personal name 2] <[personal email]>, [Company name 3]; [Personal name 9], UCL.

30-03-2017 -[Personal name 24] wrote to [Personal name 9] asking to get me involved, Stubbs replied there is no contractor appointed yet, but there will be a pre-refurbishment audit.

03-05-2017 -[Personal name 24] wrote to [Personal name 9] asking if there has been any movement -[Personal name 9] said to chase [Personal name 2] in order to get the re-refurbishment audit.

08-05-2017 -I wrote to [Personal name 2] introducing myself and asking for the audit report.

15-05-2017 -I wrote to [Personal name 2] again, [Personal name 24] replied saying [Personal name 2] asked if he could share the pre-ref audit report with me, so it should be sent shortly.

22-05-2017 -[Personal name 2] wrote to [Personal name 9] (cc'ing me) and sent the Pre-ref Audit Report.

13 March 2016
Code: CSX_01
Subject: Meeting with [Personal name 24] about UCL Here East 2

UCL HERE EAST 2 -> Real Estate Institute

Project Manager: [Company name 3]

Architects: [Company name 18]

Engineers: [Company name 8]

- **Participants** 12 people + [Personal name 24] + me
  - Me... and starting on my right side
  - [Personal name 64] (gratifying woman), UCL Project Manager
  - [Personal name 12] (sitting at the back), [Company name 8] Engineer
  - [Personal name 49] (Malaysian girl), [Company name 18] arch assistant
  - [Personal name 75], Architect no.2 (started presenting), [Company name 18]
  - Architect no.3 (woman with green eyes), [Company name 18] Engineering
  - [Personal name 44] (older guy with beard), UCL Bartlett Facilities
  - Three white guys, [Company name 1] Quantity Surveyors
  - The main architect (Scottish), [Company name 18] Engineering
  - [Personal name 24]
  - [Personal name 5], (Indian looking) [Company name 3] Project Manager
  - Young blonde guy, [Company name 8] Engineer

- **Layout**
  - There will be
    - Office space
    - Lecture theatre (80 people)
    - Breakout benches
    - Workstations + group workstations
    - Canteen
  - They’ll use fixed joinery
o There’s going to be daylight on one side (should consider that for glare)
o There are yet two layout options:
  o 3 seminar rooms + more break-out space
  o 2 seminar rooms + less break-out space
o The interior design will be similar to UCL One Canada Square

• Facilities
  o Will try to reuse air coil units
  o Might use HRMV
  o HVAC is designed for 200 people, even though the maximum would be 90
  o Will be new lighting system

• Sustainability
  o Upcoming SKA scoping session (around 27th May, before stage 3)
  o [Personal name 24] mentions HEI scheme highlights softlanding

21 March 2016
Code: CSX_02
Subject: Meeting with [Personal name 24] about upcoming fit-out projects at UCL

• Confucius Project  -->MORE WASTE GOING OUT
  o Was underbudgeted –they’ll ask for more money within the Estates
  o I can contact the architects ([Personal name 86])
  o There will be a SKA scoping session –maybe end of April

• Here East 2  -->MORE INPUTS COMING IN
  o GF –big lab for robotics engineering --£7M –targeting SKA Gold
  o 1st Floor (overlooking the lab) –Real Estate Institute –offices, seminar rooms, lecture theatre (flexible, can be one big or two small) for 40 people
  o Under feasibility stage --£1-2M
  o Not massive stripout –light fittings
  o Next meeting –SKA scoping –early May

*[Personal name 24] is going to a meeting tomorrow –Torrington Place 1-19 - Send email to remind him about details -> He has sent me an email now saying:

• Torrington Place
  o The project is focusing on a basement and ground floor level fit-out of teaching and office spaces; mainly seminar rooms, bathrooms, offices, student hub areas etc. Currently at a very early concept stage so not going to move quickly over the next month or so.

*SKA HEI –coming out end of May –this new scheme says you have to reuse at last 50% of chairs… and not only divert from landfill as in office scheme

*UCL sust team is looking to do a SKA HEI pilot soon

• Oncoming big projects:
  o Gordon Student Centre (next Bloomsbury) –works about to start, to be finished on 2018 (2.5 years) –they want to get BREEAM Outstanding
New Wilkins Refrectory + Study space (inside Main Building) –to be ready mid 2016
East UCL

+++Check website “Transforming UCL”

Extra recommendations near London to travel in weekends (May and Sep best weather):

- Brockenhurst
- Canterbury
- New forest National Park -> Isle of Wright
- Wales –North (mountains) –South (coast line)

26 September 2016
Code: CSX_03
Subject: SKA scoping session for Bloomsbury Theatre refurbishment

[Personal name 24], [Personal name 14], seven young guys, and three older (forties)

- Architect from [Company name 30]
- Project Manager, [Personal name 34], blonde, 50s, with glasses
- Operation manager UCL, [Personal name 26] (sitting at corner behind), 50s,
- UCL contract manager, [Personal name 16]
- M&E (2), [Company name 1]
- QS (2)
- Acoustician

Empty shell to be fitted-out completely
Will specify wood flooring, might REUSE timber lads?
Facade -not expecting to change it
At least two office spaces
RIPPING OUT has been done as part of other project
No work on external envelope but the roof – ventilation mechanism on top
Heating comes from district
Furniture: is already out, They have a FURNITURE INVENTORY of what was removed
Partitions: yes, linings
Stripping out doors ([Personal name 16] said, if it’s just one door it’s easier to achieve measure)
Wall coverings: yes
Hard flooring: yes
Ductwork, leaving old, putting new and connecting with old
Did not used a waste management software

In total 105 measures are targeted [or was it in scope?], and 26 are not

To get gold 79 attained in total (20 gateway out of 26)

QS says SKA scoping wouldn’t imply extra costs because measures are already in the design

Architect said project will start end of January

11 November 2016
Code: CSX_04
Subject: Bloomsbury Theatre SKA scoping BETA

At Bidborough house room 406, I was sitting next to woman with grey eyes (UCL Project manager)

Attendants: [Personal name 14], [Personal name 9] and 9 more people

D60 >Pre-refurbishment audit will be next > 15<sup>th</sup> Nov

D69 >Softlanding workshop after that. -It was mentioned someone from the estates should lead, someone that knows the building

15 November 2016
Code: CSX_05
Subject: Bloomsbury pre-refurbishment site visit

At Bloomsbury Theatre, Lower Ground, the actual theatre

Attendants: [Personal name 14], [Personal name 9] and 9 more people

  o [Personal name 27], Bloomsbury Theatre manager, glasses, talks a lot and makes jokes
  o [Personal name 74], [Company name 30] Architect, Siberian looking, pregnant, talks with shh
  o [Personal name 45], UCL Project Manager, grey eyes, well dressed
  o [Personal name 70], Australian?
  o MnE people X 3
  o Tall, young guy, surely UCL

We first met in the Foyer (main entrance) and then we went downstairs to look around the theatre: first the main auditorium, then the room next to it, then upstairs (one room and projection room), then down again to changing rooms (one small and then one big, the green room [whatever that is] in between)

It was all empty, except for the changing rooms which had chairs. I could see the following still there:

  o Carpet tiles, where the seating should be -they looked good but they said it’ll be changed because they got damaged in the strip-out [I didn’t notice] - they’re two years old
  o Some timber product, not sure what it is but I got picture
  o They mentioned TIC, but I don’t know what it is
Some steel kinda small beams
Doors for the auditorium entrance
Massive door (steel framed and timber) connecting the stage with the next room

23 May 2017
Code: CSX_06
Subject: Institute of Education (IoE) fit-out

[Personal name 24] put me in contact with [Personal name 2] and [Personal name 9], after getting no answer back, I emailed [Personal name 2] but he didn’t reply.

Finally [Personal name 2] send the pre-refurbishment audit report (see the corresponding folder) through [Personal name 9]:

- Project Manager: [Company name 3]
- BREEAM Assessor: [Company name 8]
- Audit Surveyor: [Company name 45]
E  Quantification of embodied carbon of building products

Table 0.5 provides the values of EC associated to the building components in the PRAs. ‘EC per functional unit’ is given in kgCO$_2$eq and accounts for GHG emissions during the production stage (material supply, transport to manufacturer and manufacture) of each building product. The ‘functional unit’ is the unit used in the corresponding EPDs. For example, the first item in the table is a water boiler and its EC per functional unit (kW) is 8.89 kgCO$_2$eq, where kW is the functional unit. ‘EC per unit in PRA’ is the value of EC converted into PRA units. For the case of the boiler this is obtained by multiplying the EC per functional unit (8.89 kgCO$_2$eq) by the boiler’s thermal power (23.3 kW) and equals 207.21 kgCO$_2$eq. This is the EC associated to the production of the whole boiler, which is the unit (number of items) used in the PRA. In a similar fashion, a conversion was done where the functional unit and the PRA unit differed (e.g. a conversion was made to associate kg to m or m$^2$ to number of items). To carry out these conversions, some specifications were taken from the observational diary (Appendix D) while other were assumed. The boiler’s thermal power was averaged based on the specifications given for similar products in EPDs. Thickness of floorboards and dimension of partitions were estimated based on photographs taken by the author. Dimensions of carpet tiles, ceiling tiles and wall tiles were taken from the observational diary. ‘References’ are given in the last column of the table and relate to one or more EPDs. Where more than one reference appears, EC values in EPDs were averaged for the corresponding item.

Table 0.5: EC [kgCO$_2$eq] for building products in PRAs, based on global warming potential declared in EPDs, and the corresponding references. For some items, EC values are converted into units used in the PRAs.

<table>
<thead>
<tr>
<th>Item</th>
<th>Code</th>
<th>EC per functional unit [kgCO$_2$eq]</th>
<th>Functional unit</th>
<th>EC per unit in PRA [kgCO$_2$eq]</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiler</td>
<td>SE 02</td>
<td>8.89</td>
<td>kW</td>
<td>207.21 per item</td>
<td>De Dietrich, 2019a; Uniclima, 2018</td>
</tr>
<tr>
<td>Cable duct</td>
<td>SE 05</td>
<td>1.62</td>
<td>kg</td>
<td>0.19 per m</td>
<td>Vinilchimica, 2018</td>
</tr>
<tr>
<td>Carpet tile</td>
<td>FI 02</td>
<td>9.27</td>
<td>m$^2$</td>
<td>2.32 per item</td>
<td>Desso, 2016a; Desso, 2016b; Interface, 2017</td>
</tr>
<tr>
<td>Carpet underlay: plywood</td>
<td>FI 03</td>
<td>4.38</td>
<td>m$^2$</td>
<td>1.10 per item</td>
<td>Wood Solutions, 2015</td>
</tr>
<tr>
<td>Ceiling tile</td>
<td>CL 01</td>
<td>17.62</td>
<td>m$^2$</td>
<td>6.34 per item</td>
<td>SAS International, 2014</td>
</tr>
<tr>
<td>Ceiling tile rail</td>
<td>CL 02</td>
<td>8.26</td>
<td>m$^2$</td>
<td>2.06 per m</td>
<td>SAS International, 2014</td>
</tr>
<tr>
<td>Ceiling insulation pad</td>
<td>IN 02</td>
<td>0.94</td>
<td>m$^2$</td>
<td>0.68 per item</td>
<td>Knauf Insulation, 2019</td>
</tr>
<tr>
<td>Door: timber</td>
<td>OP 01</td>
<td>52.50</td>
<td>item</td>
<td></td>
<td>Daloc, 2019; Nordic Door, 2018</td>
</tr>
<tr>
<td>Door: glazed</td>
<td>OP 01</td>
<td>38.05</td>
<td>m$^2$</td>
<td>85.50 per item</td>
<td>Ministère du logement et de l'habitat durable, 2018; Chambre Syndicale des Fabricants de Verre Plat, 2020</td>
</tr>
<tr>
<td>Fire alarm</td>
<td>SE 06</td>
<td>6.01</td>
<td>item</td>
<td></td>
<td>Ministère du Logement et de</td>
</tr>
<tr>
<td>Item</td>
<td>Code</td>
<td>EC per functional unit [kgCO₂ eq]</td>
<td>Functional unit</td>
<td>EC per unit in PRA [kgCO₂ eq]</td>
<td>References</td>
</tr>
<tr>
<td>---------------------</td>
<td>-------</td>
<td>----------------------------------</td>
<td>-----------------</td>
<td>-------------------------------</td>
<td>----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Floorboard</td>
<td>CL 03</td>
<td>1.03</td>
<td>m²</td>
<td></td>
<td>1'Habitat Durable, 2016a; BAASL, 2018</td>
</tr>
<tr>
<td>Floor finish: vinyl</td>
<td>FI 04</td>
<td>5.79</td>
<td>m²</td>
<td></td>
<td>Barlinek, 2017</td>
</tr>
<tr>
<td>Floor outlet</td>
<td>SE 08</td>
<td>7.65</td>
<td>item</td>
<td></td>
<td>Armstrong Flooring, 2014; Antico International, 2018; Tarkett, 2018a</td>
</tr>
<tr>
<td>Furniture: chair</td>
<td>FU 04</td>
<td>76.40</td>
<td>item</td>
<td></td>
<td>Herman Miller, 2016; 2019; 2020</td>
</tr>
<tr>
<td>Furniture: locker</td>
<td>FU 05</td>
<td>22.96</td>
<td>item</td>
<td></td>
<td>Bisley, 2019</td>
</tr>
<tr>
<td>Furniture: workstation</td>
<td>FU 06</td>
<td>119.80</td>
<td>item</td>
<td></td>
<td>Koleksiyon, 2018</td>
</tr>
<tr>
<td>HVAC ceiling cassette</td>
<td>SE 09</td>
<td>329</td>
<td>item</td>
<td></td>
<td>Ministère du Logement et de l'Habitat Durable, 2016b</td>
</tr>
<tr>
<td>Kitchen sink</td>
<td>KI 03</td>
<td>164</td>
<td>item</td>
<td></td>
<td>Kohler, 2020a</td>
</tr>
<tr>
<td>Light fitting</td>
<td>LI 01</td>
<td>135</td>
<td>item</td>
<td></td>
<td>Zumbotel, 2010</td>
</tr>
<tr>
<td>Light: fluorescent</td>
<td>LI 02</td>
<td>14.70</td>
<td>item</td>
<td></td>
<td>Ministère du Logement et de l'Habitat Durable, 2019a</td>
</tr>
<tr>
<td>Light: halogen</td>
<td>LI 03</td>
<td>103</td>
<td>item</td>
<td></td>
<td>Ministère du Logement et de l'Habitat Durable, 2019b</td>
</tr>
<tr>
<td>Partition: glazed</td>
<td>ST 01</td>
<td>61.10</td>
<td>m²</td>
<td>281 per item</td>
<td>AGC, 2020</td>
</tr>
<tr>
<td>Partition: plasterboard</td>
<td>ST 02</td>
<td>1.60</td>
<td>m²</td>
<td>7.36 per item</td>
<td>Dalsan, 2018; Etex, 2018; Winstone Wallboards, 2018</td>
</tr>
<tr>
<td>Radiator</td>
<td>SE 11</td>
<td>67.80</td>
<td>item</td>
<td></td>
<td>Chapee 2019; De Dietrich, 2019b</td>
</tr>
<tr>
<td>RAF</td>
<td>CL 04</td>
<td>61.03</td>
<td>m²</td>
<td>21.97 per item</td>
<td>Kingspan Access Floors, 2016; Global IFS; 2020</td>
</tr>
<tr>
<td>Socket: electrical</td>
<td>SE 12</td>
<td>0.91</td>
<td>item</td>
<td></td>
<td>Schneider Electric, 2008</td>
</tr>
<tr>
<td>Socket: ethernet</td>
<td>SE 13</td>
<td>0.91</td>
<td>item</td>
<td></td>
<td>Schneider Electric, 2008</td>
</tr>
<tr>
<td>Toilet bowl</td>
<td>TO 01</td>
<td>154</td>
<td>item</td>
<td></td>
<td>Kohler, 2014; 2018; 2020b</td>
</tr>
<tr>
<td>Toilet dryer</td>
<td>TO 04</td>
<td>8.81</td>
<td>item</td>
<td></td>
<td>Excel, 2016</td>
</tr>
<tr>
<td>Toilet sink</td>
<td>TO 05</td>
<td>66.40</td>
<td>item</td>
<td></td>
<td>AFISB, 2014; American Standard, 2018a; AFISB, 2020</td>
</tr>
<tr>
<td>Toilet urinal</td>
<td>TO 06</td>
<td>42.60</td>
<td>item</td>
<td></td>
<td>American Standard, 2018b</td>
</tr>
<tr>
<td>Wall paper</td>
<td>FI 09</td>
<td>4.26</td>
<td>m²</td>
<td></td>
<td>Tarkett, 2018b</td>
</tr>
</tbody>
</table>
Table 0.6 presents the EC calculated for each of the building products in the PRA for UCL Confucius Institute. The ‘item’ column specifies the building product and is followed by its ‘code’ (refer to subsection 3.2.4 to see code list). The ‘quantity’ normally specifies the number of items, but it can also be given in m or m², depending on the type of product. The ‘destination’ accounts for the pathway followed by each product, which may include being taken by Waste Contractor, retaining in situ or onsite/offsite reuse. ‘EC’ is given in kgCO₂eq and is obtained by multiplying the corresponding value of EC per unit in PRA (in Table 0.5) by the quantity. For example, the EE per unit in PRA for the boiler (207.21 kgCO₂eq per item) multiplied by the quantity (2 items) equals 414 kgCO₂eq. The ‘share of EC’ is the contribution of the enlisted item(s) relative to the total EC, where total EC (18,403 kgCO₂eq) is the sum of EC for all items in the PRA. ‘Saved EC’ relates to the EC savings due to items being retained or reused.

Table 0.6: Share [%] of EC per item (relative to the total fit-out EC) and saved EC [kgCO₂eq] due to retention and reuse of building products, for UCL Confucius Institute fit-out.

<table>
<thead>
<tr>
<th>Item</th>
<th>Code</th>
<th>Quantity</th>
<th>Destination</th>
<th>EC [kgCO₂eq]</th>
<th>Share of EC</th>
<th>Saved EC [kgCO₂eq]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blackboard</td>
<td>FU 01</td>
<td>5</td>
<td>WC</td>
<td>N/A</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Boiler</td>
<td>SE 02</td>
<td>2</td>
<td>WC</td>
<td>414</td>
<td>2%</td>
<td></td>
</tr>
<tr>
<td>Cableduct [m]</td>
<td>SE 05</td>
<td>151</td>
<td>WC</td>
<td>29</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>Carpet tile</td>
<td>FI 02</td>
<td>1360</td>
<td>WC</td>
<td>3155</td>
<td>17%</td>
<td></td>
</tr>
<tr>
<td>Carpet underlay: plywood</td>
<td>FI 03</td>
<td>1360</td>
<td>WC</td>
<td>1496</td>
<td>8%</td>
<td></td>
</tr>
<tr>
<td>Cloth hanger</td>
<td>FU 02</td>
<td>3</td>
<td>WC</td>
<td>N/A</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>Door</td>
<td>OP 01</td>
<td>22</td>
<td>8 RET/14 WC</td>
<td>1155</td>
<td>6%</td>
<td>420</td>
</tr>
<tr>
<td>Door frame</td>
<td>OP 02</td>
<td>22</td>
<td>17 RET/5 WC</td>
<td>N/A</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>Fire alarm</td>
<td>SE 06</td>
<td>5</td>
<td>WC</td>
<td>30</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>Fire extinguisher</td>
<td>SE 07</td>
<td>8</td>
<td>ROF</td>
<td>N/A</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>Floorboards [m²]</td>
<td>CL 03</td>
<td>218</td>
<td>206 RET/12 WC</td>
<td>224</td>
<td>1%</td>
<td>212</td>
</tr>
<tr>
<td>Floor finish: vinyl [m²]</td>
<td>FI 04</td>
<td>5</td>
<td>WC</td>
<td>29</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>Kitchen counter [m]</td>
<td>KI 01</td>
<td>6</td>
<td>WC</td>
<td>N/A</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>Kitchen cupboards</td>
<td>KI 02</td>
<td>14</td>
<td>WC</td>
<td>N/A</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>Kitchen sink</td>
<td>KI 03</td>
<td>2</td>
<td>WC</td>
<td>328</td>
<td>2%</td>
<td></td>
</tr>
<tr>
<td>Light fitting</td>
<td>LI 01</td>
<td>30</td>
<td>WC</td>
<td>4050</td>
<td>22%</td>
<td></td>
</tr>
</tbody>
</table>
### Table 0.7: Share [%] of EC per item (relative to the total fit-out EC) and saved EC [kgCO2eq] due to retention and reuse of building products, for UCL Central House fit-out.

<table>
<thead>
<tr>
<th>Item</th>
<th>Code</th>
<th>Quantity</th>
<th>Destination</th>
<th>EC [kgCO2eq]</th>
<th>Share of EC</th>
<th>Saved EC [kgCO2eq]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cable: electrical [m]</td>
<td>SE 03</td>
<td>-</td>
<td>WC</td>
<td>N/A</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Cable: ethernet [m]</td>
<td>SE 04</td>
<td>-</td>
<td>WC</td>
<td>N/A</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Carpet tile</td>
<td>FI 02</td>
<td>926</td>
<td>WC</td>
<td>2148</td>
<td>4%</td>
<td></td>
</tr>
<tr>
<td>Ceiling tile</td>
<td>CL 01</td>
<td>489</td>
<td>WC</td>
<td>3100</td>
<td>6%</td>
<td></td>
</tr>
<tr>
<td>Ceiling tile rail [m]</td>
<td>CL 02</td>
<td>660</td>
<td>WC</td>
<td>332</td>
<td>1%</td>
<td></td>
</tr>
<tr>
<td>Ceiling insulation pad</td>
<td>IN 02</td>
<td>489</td>
<td>WC</td>
<td>332</td>
<td>1%</td>
<td></td>
</tr>
</tbody>
</table>

Table 0.7 shows the EC calculated for each of the building products in the PRA for UCL Central House. Calculations were performed following the procedure explained earlier for Table 0.6. The total EC for this case study resulted in 54,095 kgCO2eq.
<table>
<thead>
<tr>
<th>Item</th>
<th>Code</th>
<th>Quantity</th>
<th>Destination</th>
<th>EC [kgCO2eq]</th>
<th>Share of EC</th>
<th>Saved EC [kgCO2eq]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Door: timber</td>
<td>OP 01</td>
<td>6</td>
<td>WC</td>
<td>315</td>
<td>1%</td>
<td></td>
</tr>
<tr>
<td>Door: glazed</td>
<td>OP 01</td>
<td>3</td>
<td>WC</td>
<td>256</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>Door: wardrobe</td>
<td>OP 01</td>
<td>8</td>
<td>RET</td>
<td>N/A</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>Fire alarm</td>
<td>SE 06</td>
<td>5</td>
<td>WC</td>
<td>30</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>Fire extinguisher</td>
<td>SE 07</td>
<td>2</td>
<td>RET</td>
<td>N/A</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>Floor outlet: round</td>
<td>SE 08</td>
<td>40</td>
<td>WC</td>
<td>306</td>
<td>1%</td>
<td></td>
</tr>
<tr>
<td>Floor outlet: square</td>
<td>SE 08</td>
<td>6</td>
<td>WC</td>
<td>46</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>Floor outlet: socket</td>
<td>SE 08</td>
<td>12</td>
<td>WC</td>
<td>92</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>Furniture: chair</td>
<td>FU 04</td>
<td>33</td>
<td>STO</td>
<td>2512</td>
<td>5%</td>
<td>2512</td>
</tr>
<tr>
<td>Furniture: locker</td>
<td>FU 05</td>
<td>33</td>
<td>STO</td>
<td>758</td>
<td>1%</td>
<td>758</td>
</tr>
<tr>
<td>Furniture: workstation</td>
<td>FU 06</td>
<td>33</td>
<td>STO</td>
<td>3953</td>
<td>7%</td>
<td>3953</td>
</tr>
<tr>
<td>HVAC ceiling cassette</td>
<td>SE 09</td>
<td>14</td>
<td>6 RET/8 STO</td>
<td>4606</td>
<td>9%</td>
<td>4606</td>
</tr>
<tr>
<td>HVAC ductwork</td>
<td>SE 10</td>
<td>-</td>
<td>WC</td>
<td>N/A</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>Light fitting: square</td>
<td>LI 01</td>
<td>72</td>
<td>WC</td>
<td>9720</td>
<td>18%</td>
<td></td>
</tr>
<tr>
<td>Light fitting: round</td>
<td>LI 01</td>
<td>9</td>
<td>WC</td>
<td>1215</td>
<td>2%</td>
<td></td>
</tr>
<tr>
<td>Light: fluorescent</td>
<td>LI 02</td>
<td>216</td>
<td>WC</td>
<td>3175</td>
<td>6%</td>
<td></td>
</tr>
<tr>
<td>Light: halogen</td>
<td>LI 03</td>
<td>9</td>
<td>WC</td>
<td>927</td>
<td>2%</td>
<td></td>
</tr>
<tr>
<td>Partition: glazed</td>
<td>ST 01</td>
<td>1</td>
<td>WC</td>
<td>281</td>
<td>1%</td>
<td></td>
</tr>
<tr>
<td>Partition: plasterboard</td>
<td>ST 02</td>
<td>4</td>
<td>WC</td>
<td>29</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>RAF tiles</td>
<td>CL 04</td>
<td>747</td>
<td>695 RET/52</td>
<td>16412</td>
<td>30%</td>
<td>15270</td>
</tr>
<tr>
<td>Socket: electrical</td>
<td>SE 12</td>
<td>14</td>
<td>WC</td>
<td>13</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>Toilet bowl</td>
<td>TO 01</td>
<td>3</td>
<td>RET</td>
<td>462</td>
<td>1%</td>
<td>462</td>
</tr>
<tr>
<td>Toilet paper dispenser</td>
<td>TO 02</td>
<td>3</td>
<td>RET</td>
<td>N/A</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>Toilet soap dispenser</td>
<td>TO 03</td>
<td>2</td>
<td>RET</td>
<td>N/A</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>Toilet dryer</td>
<td>TO 04</td>
<td>1</td>
<td>RET</td>
<td>9</td>
<td>0%</td>
<td>9</td>
</tr>
<tr>
<td>Toilet radiator</td>
<td>SE 11</td>
<td>1</td>
<td>RET</td>
<td>68</td>
<td>0%</td>
<td>68</td>
</tr>
<tr>
<td>Toilet sink</td>
<td>TO 05</td>
<td>3</td>
<td>RET</td>
<td>199</td>
<td>0%</td>
<td>199</td>
</tr>
<tr>
<td>Toilet urinal</td>
<td>TO 06</td>
<td>3</td>
<td>RET</td>
<td>128</td>
<td>0%</td>
<td>128</td>
</tr>
<tr>
<td>Window blinds</td>
<td>OP 03</td>
<td>22</td>
<td>WC</td>
<td>N/A</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>Window frame</td>
<td>OP 05</td>
<td>22</td>
<td>RET</td>
<td>3003</td>
<td>6%</td>
<td>3003</td>
</tr>
<tr>
<td>Window pane</td>
<td>OP 06</td>
<td>22</td>
<td>RET</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL EC</strong></td>
<td></td>
<td></td>
<td></td>
<td>54095</td>
<td>30968</td>
<td></td>
</tr>
</tbody>
</table>
F Development of the material flow analysis diagrams

F.1 Waste stream pathways and final destinations

The pathways and the final destinations defined for the waste streams generated at fit-out projects are mainly based on data provided by Waste Contactor 1. Table 0.8 shows the different ‘materials’ and ‘components’, along with the corresponding ‘EWC’ code, the direct ‘intermediary’ where waste streams are sent for onward processing and/or delivery (i.e. Waste Dealer or MRF), and the different destinations where each waste stream is taken to. Most of the destinations are located within the UK, or otherwise the country of the destination is specified.

The data shown in Table 0.8 is result from interaction with this Waste Contractor from September 2016 to July 2017. Some of the data was ratified or rectified with Waste Dealers when possible. The personal communications with these downstream stakeholders are shown in the Observational diary (Appendix D).

F.2 SankeyMATIC scripts to create the MFA diagrams

The MFA diagrams for four of the fit-out case studies were produced using the online tool SankeyMATIC (2018). The scripts shown below were input in the online tool for each case study to generate the corresponding MFA diagram.

F.2.1 Bank offices

' Bank offices > [Company name 26]

' 20-07-2019

'***** DESIGN PARAMETRES

'900x600, flow opacity three steps before 1.0, no full precision for labels, bold labels, suffix 't', node opacity 1.0

'***** TRANSFER SITE COLOUR

'For segregated waste>: #5D6D7E

'RESIGN, For mixed waste>: #5D6D7E

'---------------NOT SEGREGATED----------

'I used the following shares for splitting mixed waste, based on WC1 shares

<table>
<thead>
<tr>
<th>WASTE 'STREAM SHARE [%]</th>
<th>Rel. share</th>
<th>Bank fitout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulation 0.4 0.02 0.19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plastic 0.4 0.02 0.19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Textiles 0.4 0.02 0.19</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
'Hardcore  2  0.11  0.95
'Metals  2  0.11  0.95
'Wood  13  0.71  6.15
'      18.2  1  8.62

***** MIXED WASTE (8.8t)
: Mixed waste #59484F
Mixed waste [8.8] , #59484F
'> Breakdown of Mixed waste, 2% landfilled
, [0.18] Landfill #59484F
, [0.95] Hardcore collector #BBB8B2
, [0.19] Insulation collector #A37774
, [0.95] Metals collector #247BA0
, [0.19] Plastics collector #CC5543
, [0.19] Textiles collector #6D7696
, [6.15] Wood collector #82AC9F

*** Textiles [from Mixed waste]
: Textiles collector #6D7696
Textiles collector [0.19] Textile industry #6D7696

---------------------

***** WOOD (3.40t) [joined with MW]
: Wood #82AC9F
: Wood collector #82AC9F
Wood [3.40] 1 #82AC9F
1 [3.40] Wood collector #82AC9F
'>> From 3.40t + 6.15t of Wood: 100%:
'>> From 9.55t of Wood: 70,30%
Wood collector [6.68] Chipboard manufacture, Belgium #82AC9F
Wood collector [2.87] Energy recovery, Belgium #82AC9F
***** INSULATION (0.20t) [joined with MW]
:Insulation #A37774
:Insulation collector #A37774
Insulation [0.20] 1 #A37774
1 [0.20] Insulation collector #A37774
'>> From 0.20t + 0.19t of Insulation: 100%
Insulation collector [0.39] Multiple industries #A37774

***** PLASTICS (1.61t) [joined with MW]
:Plastics #CC5543
:Plastics collector #CC5543
Plastics [0.40] 1 #CC5543
1 [0.40] Plastics collector #CC5543
'>> From 0.40t + 0.19t of Plastics: 100%
Plastics collector [0.59] Plastics industry, China #CC5543

***** METALS (4.70t) [joined with MW]
:Metals #247BA0
:Metals collector #247BA0
Metals [4.70] 1 #247BA0
1 [4.70] Metals collector #247BA0
'>> From 4.70t + 0.95t of Metals: 100%
Metals collector [5.65] Metals industry, Spain/Turkey #247BA0

***** HARDCORE (2.00t) [joined with MW]
:Hardcore #BBB8B2
:Hardcore collector #BBB8B2
Hardcore [2.00] 1 #BBB8B2
1 [2.00] Hardcore collector #BBB8B2
'>> From 2.00t + 0.95t of Hardcore: 100%:
'>> From 2.95t of Hardcore: 50,50%:
Hardcore collector [1.48] Construction industry #BBB8B2
Hardcore collector [1.47] Landscaping industry #BBB8B2

***** CARDBOARD (0.10t) [joined with Paper]
Cardboard [0.10] 1 #826251
1 [0.10] Paper & Cardboard collector #826251

'>> From 0.10t + 1.60t of Paper: 100%
Paper & Cardboard collector [1.70] Various paper mills #826251

***** PAPER (1.60t) [already joined with Cardboard]
Paper [1.60] 1 #826251
1 [1.60] Paper & Cardboard collector #826251

***** PLASTERBOARD (16.10t)
Plasterboard [16.10] 1 #EDB579
1 [16.10] Plasterboard collector #EDB579

'>> From 16.10t of Plasterboard: 60,20,20% (pondering MSK and Berymann):
Plasterboard collector [9.66] Plasterboard manufacture #EDB579
Plasterboard collector [3.22] Cement manufacture #EDB579
Plasterboard collector [3.22] Agriculture compost #EDB579

F.2.2 UKGBC offices
' UKGBC offices > [Company name 29]
' 11-04-2018
***** DESIGN PARAMETRES

'900x600, flow opacity three steps before 1.0, no full precision for labels, bold labels, suffix 't', node opacity 1.0

***** TRANSFER SITE COLOUR

'For mixed waste>
: #5D6D7E

'For office furniture>
: #5D6D7E

'For Segregated>
:1 #5D6D7E

---------------MIXED WASTE----------

***** MIXED WASTE (1.17t)

: Mixed waste #59484F

Mixed waste [1.17] , #59484F

> Breakdown of Mixed waste, 1.7% landfilled -MSK shares, considering less for wood> 23% wood, 22% metals, 11% hardcore, 11% P&C, 11% Plastics, 11% Textiles

, [0.02] Landfill #59484F

, [0.13] Paper & Cardboard collector #826251

, [0.13] Plastics collector #CC5543

[Plastics joined with MW]

, [0.25] Hardcore collector #BBB8B2

, [0.25] Metals collector #247BA0

[Metals joined with MW]

, [0.13] Textiles collector #6D7696

[Textiles joined with MW]

, [0.26] Wood collector #82AC9F

[Wood joined with OF and Wood]

***** Paper & Cardboard (0.13t)

: Paper & Cardboard collector #826251
Appendices

Paper & Cardboard collector [0.13] Various paper mills #826251

'***** Hardcore (0.25t)
:Hardcore collector #BBB8B2
'>> From 0.25t of Hardcore: 50,50%:
Hardcore collector [0.125] Construction industry #BBB8B2
Hardcore collector [0.125] Landscaping industry #BBB8B2
'-------------------------------------------------

'--------------OFFICE FURNITURE-------------
'***** OFFICE FURNITURE (0.28t)
:Office furniture #9F9F92
Office furniture [0.28] . #9F9F92
' > Breakdown of Office furniture, 25% Plastics, 25% Metals, 25% Textiles, 25% Wood
. [0.07] Plastics collector #CC5543
. [0.07] Metals collector #247BA0
. [0.07] Textiles collector #6D7696
. [0.07] Wood collector #82AC9F
'[Wood joined with Wood]

'***** Plastics (0.07t)
:Plastics collector #CC5543
'>> From 0.13t + 0.07t of Plastics: 100%
Plastics collector [0.20] Plastics industry, China #CC5543

'***** Metals (0.07t)
:Metals collector #247BA0
'>> From 0.25t + 0.07t of Plastics: 100%
Metals collector [0.32] Metals industry, Spain/Turkey #247BA0

'***** Textiles (0.07t)
Appendices

Textiles collector #6D7696

>> From 0.13t + 0.07t of Textiles: 100%
Textiles collector [0.20] Textile industry #6D7696

-------------------------------------------------

***** WOOD (0.48t) [joined with MW and OF]

:Wood #82AC9F
:Wood collector #82AC9F
Wood [0.48] 1 #82AC9F
1 [0.48] Wood collector #82AC9F

>> From 0.26 + 0.07t + 0.48t of Wood (0.81): 70.30%
Wood collector [0.57] Chipboard manufacture, Belgium #82AC9F
Wood collector [0.24] Energy recovery, Belgium #82AC9F

***** INSULATION (0.20t)

:Insulation #A37774
:Insulation collector #A37774
Insulation [0.20] 1 #A37774
1 [0.20] Insulation collector #A37774

>> From 0.20t of Insulation: 100%
Insulation collector [0.20] Multiple industries #A37774

***** PLASTERBOARD (1.68t)

:Plasterboard #EDB579
:Plasterboard collector #EDB579
:Plasterboard manufacture #EDB579
Plasterboard [1.68] 1 #EDB579
1 [1.68] Plasterboard collector #EDB579

>> From 1.68t of Plasterboard: 60,20,20% (pondering MSK and Berymann):
Plasterboard collector [1.00] Plasterboard manufacture #EDB579
Plasterboard collector [0.34] Cement manufacture #EDB579
Appendices

Plasterboard collector [0.34] Agriculture compost #EDB579

F.2.3 UCL Confucius Institute
' UCL Confucius > [Company name 26]
' 22-02-2018
' modified as SWMP figures were wrong
***** DESIGN PARAMETRES
'900x600, flow opacity three steps before 1.0, no full precision for labels, bold labels, suffix ‘t’, node opacity 1.0

***** TRANSFER SITE COLOUR
'For segregated waste>
:1 #5D6D7E
'For mixed waste>
:, #5D6D7E

'------------------NOT SEGREGATED-----------------
***** MIXED WASTE (7.32t) done
:Mixed waste #59484F
Mixed waste [7.32] , #59484F
' Breakdown of Mixed waste, 35% landfilled
, [2.56] Landfill #59484F
, [1.60] Metals collector #247BA0
, [1.58] Paper & Cardboard collector #826251
, [1.58] Plastics collector #CC5543

*** Paper & Cardboard [from Mixed waste]
: Paper & Cardboard collector #826251
Paper & Cardboard collector [1.58] Various paper mills #826251

***** PLASTICS (1.61t) [joined with MW]
Appendices

:Plastics #CC5543
:Plastics collector #CC5543
Plastics [1.61] 1 #CC5543
1 [1.61] Plastics collector #CC5543
'>> From 1.61t + 1.58t of Plastics: 100%
Plastics collector [3.19] Plastics industry, China #CC5543

***** METALS (2.49t) [joined with MW]
:Metals #247BA0
:Metals collector #247BA0
Metals [2.49] 1 #247BA0
1 [2.49] Metals collector #247BA0
'>> From 2.49t + 1.60t of Metals: 100%:
Metals collector [4.09] Metals industry, Spain/Turkey #247BA0

***** TEXTILES (2.65t)
:Textiles #6D7696
:Textiles collector #6D7696
Textiles [2.65] 1 #6D7696
1 [2.65] Textiles collector #6D7696
'>> From 2.65t of Textiles: 95,5%:
Textiles collector [2.51] Textile industry #6D7696
Textiles collector [0.14] Landfill #6D7696

***** GLASS (1.39t)
:Glass #B4BD90
:Glass collector #B4BD90
Glass [1.39] 1 #B4BD90
1 [1.39] Glass collector #B4BD90
'>> From 1.39t of Glass: 90,10% (originally 88,7%):
Glass collector [1.25] Glass products #B4BD90
Glass collector [0.14] Building blocks aggregate #B4BD90

***** PLASTERBOARD (2.50t)
:Plasterboard #EDB579
:Plasterboard collector #EDB579
Plasterboard [2.50] 1 #EDB579
1 [2.50] Plasterboard collector #EDB579
'>> From 2.50 t of Plasterboard: 60,20,20% (pondering MSK and Berymann):
Plasterboard collector [1.50] Plasterboard manufacture #EDB579
Plasterboard collector [0.50] Cement manufacture #EDB579
Plasterboard collector [0.50] Agriculture compost #EDB579

***** WOOD (7.36t)
:Wood #82AC9F
:Wood collector #82AC9F
Wood [7.36] 1 #82AC9F
1 [7.36] Wood collector #82AC9F
'>> From 7.36t of Wood: 70,30%
Wood collector [5.15] Chipboard manufacture, Belgium #82AC9F
Wood collector [2.21] Energy recovery, Belgium #82AC9F

***** HARDCORE (9.47t)
:Hardcore #BBB8B2
:Hardcore collector #BBB8B2
Hardcore [9.47] 1 #BBB8B2
1 [9.47] Hardcore collector #BBB8B2
'>> From 9.47t of Hardcore: 50,50%:
Hardcore collector [4.735] Construction industry #BBB8B2
Hardcore collector [4.735] Landscaping industry #BBB8B2

***** ABESTOS (0.49t)
Asbestos

'>> From 0.49t of Asbestos: 100%:
Asbestos [0.49] Direct deep landfill burial

**F.2.4  UCL Central House**

' UCL Central House > [Company name 26]

' 10-04-2018

***** DESIGN PARAMETRES

'900x600, flow opacity three steps before 1.0, no full precision for labels, bold labels, suffix ‘t’, node opacity 1.0

***** TRANSFER SITE COLOUR

'For mixed waste:
.; #5D6D7E

'For mixed packaging:
.; #5D6D7E

'For pasterboard:
;1 #5D6D7E

'------------------------MIXED WASTE------------------------

***** MIXED WASTE (4.74t)

'Mixed waste #59484F
Mixed waste [4.74] , #59484F

' > Breakdown of Mixed waste, 3% landfilled -MSK shares> wood 65%, metals 10, hardcore 10, P&C 5, Plastics 5, Textiles 5

; [0.13] Landfill #59484F
; [0.23] Paper & Cardboard collector #826251
; [0.23] Plastics collector #CC5543
; [0.46] Hardcore collector #BBB8B2
; [0.46] Metals collector #247BA0
; [0.23] Textiles collector #6D7696
; [3.00] Wood collector #82AC9F
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'**** Paper & Cardboard (0.23t) [joined with MP]

'***** Plastics (0.23t) [joined with MP]

'***** Hardcore (0.46t)
:Hardcore collector #BBB8B2
'>> From 0.46t of Hardcore: 50,50%:
Hardcore collector [0.23] Construction industry #BBB8B2
Hardcore collector [0.23] Landscaping industry #BBB8B2

'***** Metals (0.46t)
:Metals collector #247BA0
Metals collector [0.46] Metals industry, Spain/Turkey #247BA0

'***** Textiles (0.23t)
:Textiles collector #6D7696
Textiles collector [0.23] Textile industry #6D7696

'***** Wood (3.00t)
:Wood collector #82AC9F
'>> From 3.00t of Wood: 70,30%
Wood collector [2.10] Chipboard manufacture, Belgium #82AC9F
Wood collector [0.90] Energy recovery, Belgium #82AC9F

'-------------------------------------------------

'---------------MIXED PACKAGING----------

'***** MIXED PACKAGING (0.42t)
:Mixed packaging #A07178
Mixed packaging [0.42]. #A07178
'> Breakdown of Mixed waste, 50% P&C, 50% Plastics
Appendices

***** Paper & Cardboard (0.21t) [joined with MW]
:Paper & Cardboard collector #826251
  . [0.21] Paper & Cardboard collector #826251
'>> From 0.21t + 0.23t of Paper: 100%
Paper & Cardboard collector [0.44] Various paper mills #826251

***** Plastics (0.21t) [joined with MW]
:Plastics collector #CC5543
  . [0.21] Plastics collector #CC5543
'>> From 0.21t + 0.23t of Plastics: 100%
Plastics collector [0.44] Plastics industry, China #CC5543

-------------------------------------------------

***** PLASTERBOARD (1.22t)
:Plasterboard #EDB579
:Plasterboard collector #EDB579
:Plasterboard manufacture #EDB579
Plasterboard [1.22] 1 #EDB579
1 [1.22] Plasterboard collector #EDB579
'>> From 1.22 t of Plasterboard: 60,20,20% (pondering MSK and Berymann):
Plasterboard collector [0.72] Plasterboard manufacture #EDB579
Plasterboard collector [0.25] Cement manufacture #EDB579
Plasterboard collector [0.25] Agriculture compost #EDB579
Table 0.8: Destinations of each waste stream (personal communications with Waste Contractor 1, 2016; 2017).

<table>
<thead>
<tr>
<th>WASTE STREAM</th>
<th>COMPANY NAME</th>
<th>1ST DESTINATION</th>
<th>2ND DESTINATION</th>
<th>3RD DESTINATION</th>
<th>4TH DESTINATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ceiling tiles</td>
<td>[Company name 29]</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Suspended ceiling tiles</td>
<td>[Company name 29]</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Raised access floor tiles</td>
<td>[Company name 29]</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Unreclaimed furniture</td>
<td>[Company name 29]</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Fluorescent tubes</td>
<td>[Company name 29] Barking facilities</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Insulation (polystyrene)</td>
<td>[Company name 29]</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Flooring offcuts</td>
<td>[Company name 29]</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Fire extinguisher</td>
<td>[Company name 46]</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Fire alarm</td>
<td>[Company name 43]</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Electrical socket</td>
<td>[Company name 47]</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Recovered carpets</td>
<td>[Company name 61], Belgium</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Bateries</td>
<td>[Company name 29]</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Appliances</td>
<td>[Company name 61], Belgium</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Wood (including fibreboard)</td>
<td>[Company name 29]</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Metals - Non-ferrous</td>
<td>[Company name 29]</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Metals - Ferrous</td>
<td>[Company name 29]</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
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<tr>
<td>WEEE</td>
<td>[Company name 60]</td>
<td>NA</td>
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<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Plasterboard (gypsum)</td>
<td>[Company name 29]</td>
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<td>NA</td>
<td>NA</td>
<td>NA</td>
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<tr>
<td>Pallets</td>
<td>[Company name 29]</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Paper &amp; Cardboard</td>
<td>[Company name 61], Belgium</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Paint, adhesive, etc.</td>
<td>[Company name 51], [Company name 39], [Company name 60], [Company name 39], [Company name 51]</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
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<tr>
<td>Paint containing hazardous substances</td>
<td>[Company name 51]</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Textiles</td>
<td>[Company name 61], Belgium</td>
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<td>NA</td>
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<tr>
<td>Fibreboard</td>
<td>[Company name 28]</td>
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<tr>
<td>Hardcore</td>
<td>[Company name 29]</td>
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<td>NA</td>
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<tr>
<td>Asbestos</td>
<td>[Company name 51]</td>
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<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Mixed waste</td>
<td>[Company name 29]</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
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</tr>
</tbody>
</table>

Comments: This chart shows the destinations and intermediaries for common waste streams. Shown percentages are only estimated averages.
G  Initial communication to potential interviewees

G.1  Generic email sent
Most of the potential interviewees were firstly contacted via email. An example of a generic message sent to potential interviewees is presented below, although different messages were sent according to the type of interviewee and the information that was enquired after.

Dear [name],

I hope this email finds you well. [Person who provided the reference] ([company they work on and position in the company]) kindly provided me your contact. I would like to ask you, if possible, for some support in the following matter.

I’m a UCL student working on a doctoral project on circular economy in office building fit-outs. My aim is to follow up the different waste streams arising from fit-out processes and dig into where the waste goes, and what it becomes when it’s recycled/reused.

I’d really appreciate it if you would have a moment for a quick chat regarding waste management in fit-out projects. I have prepared a Q&A which shouldn’t take longer than 30 mins to answer.

Many thanks for your consideration.

Kind regards,
[Author’s name]

G.2  Project brief
Initial verbal and written communication to potential interviewees included the following paragraph to introduce the basis aims of the research project. The paragraph below was modified when required according to the situation.

The project “Circular Economy in Office Building Fit-outs” is carried out in the UCL Environmental Design and Engineering Institute, by the PhD student Miguel Casas and supervised by Dr Ben Croxford. The project aims to trace the paths of different waste streams throughout the supply chain involved in fit-out projects and to define the relations among supply-chain actors in order to identify potential improvements regarding sustainability. We appreciate your collaboration; all information will be treated as confidential.